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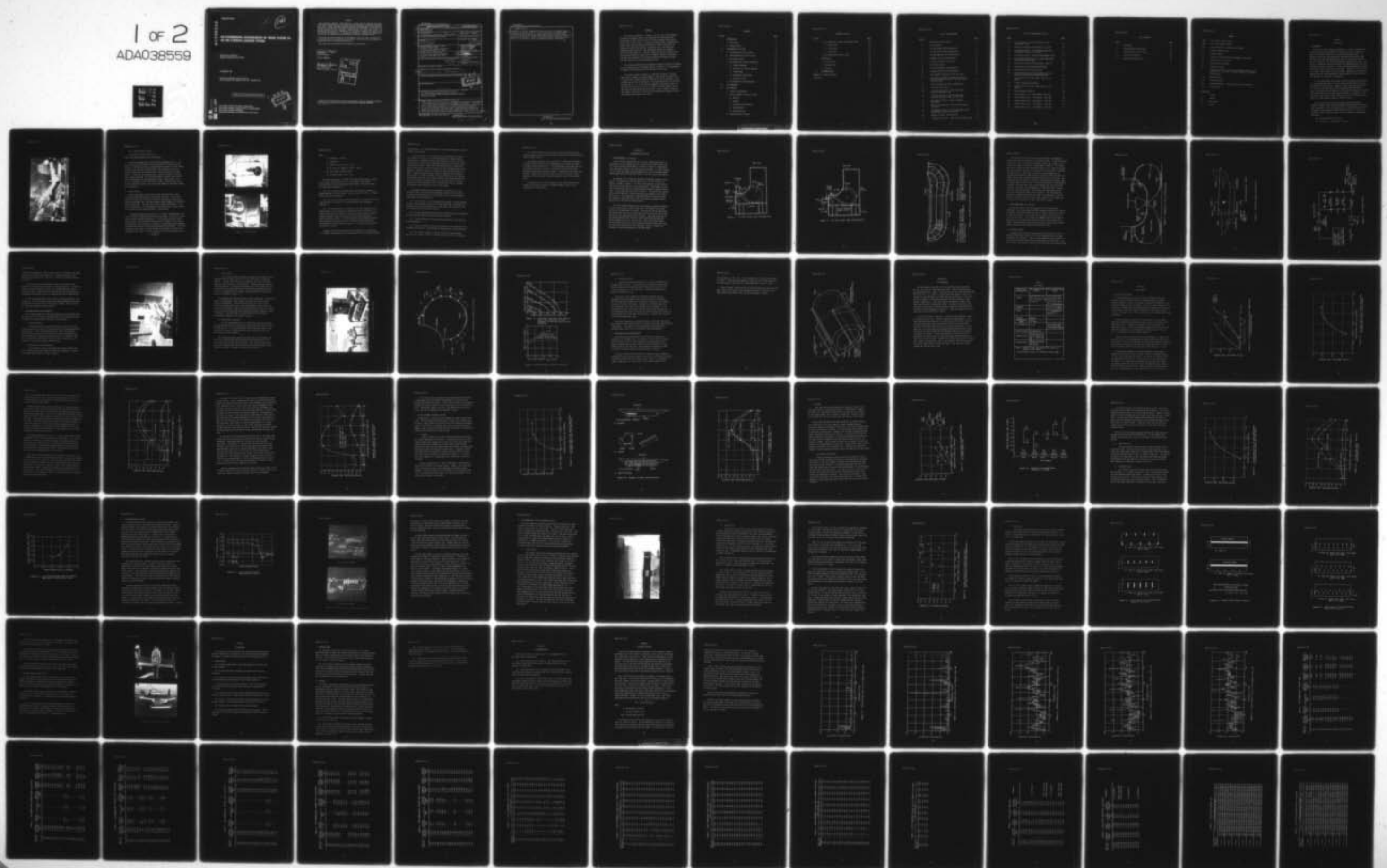

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AN EXPERIMENTAL INVESTIGATION OF TRUNK FLUTTER OF AN AIR CUSHION LANDING SYSTEM

MECHANICAL BRANCH
VEHICLE EQUIPMENT DIVISION

NOVEMBER 1976

TECHNICAL REPORT AFFDL-TR-75-107
FINAL REPORT FOR PERIOD JUNE 1974 - MARCH 1975

Approved for public release; distribution unlimited

AIR FORCE FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this work was to experimentally investigate the phenomenon of air cushion vehicle trunk flutter and attempt to eliminate it. The occurrence of trunk flutter was found to be eliminated with the use of tread strips (1/2 in.-wide pieces of rubber, cut to certain lengths and thicknesses) attached to the bottom of the trunk tread. These strips form channels when placed side-by-side that allow the flutter-producing cushion air to escape from beneath the vehicle without causing trunk flutter. This flutter → next page

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20. ABSTRACT (Cont'd)

elimination device can be employed without the loss of the required cushion pressure or an increase of the drive air flow into the air cushion system. It is recommended that a dynamic air cushion system that is known to exhibit flutter, be designed with a trunk tread having permanently affixed tread strips. These tests are needed to confirm the successful flutter eliminating characteristics of tread strips, which are statically tested in this report.

FOREWORD

This work was conducted in support of an Air Force Flight Dynamics Laboratory development effort, and concerned the investigation and elimination of trunk flutter of the air cushion landing system (ACLS) used on the Jindivik drone. The work was accomplished in the Mechanical Branch (FEM), Vehicle Equipment Division, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. The effort was conducted under Project No. 1369 "Mechanical Systems for Advanced Military Flight Vehicles," Task No. 136902" Air Cushion Landing System for Aerospace Vehicles," Work Unit No. 13690214 "Analysis, Laboratory Testing, and Evaluation of Air Cushion Take-off and Recovery System." The time span was June 1974 through March 1975.

The author performed this experimental program in partial fulfillment of the requirements for the degree, Master of Science, in the Department of Mechanical Engineering from the Ohio State University.

The author wishes to express his gratitude to James T. Steiger, Major John C. Vaughan III, Shade Campbell, Kirk Barret, and David Pool of the Air Force Flight Dynamics Laboratory for their assistance in the accomplishment of the test program. The author would also like to thank his adviser, Dr. Lit S. Han, for his suggestion to perform research in this new and interesting field of air cushion landing systems, and for the advice he gave during the thesis work. Lastly, thanks is given to the author's supervisors in the Air Force Aeronautical Systems Division, who allowed him to perform this work.

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SYMBOLS

ACRS	air cushion recovery system
ACTS	air cushion takeoff system
Amp	flutter amplitude, peak-to-peak (inches)
f	flutter frequency (cps)
FS	fuselage station
g_o	Constant of proportionality and Newton's Second Law
G	acceleration (rms, ft/sec^2)
m	mass flow rate (lbm/sec)
$\dot{m}_c$	cushion mass flow
P	Pressure (lbf/in^2), used for the following gage pressures: cushion (P_c), trunk (P_t), ejector drive (P_e), and fan primary (P_{fp})
2-D	two-dimensional
3-D	three-dimensional
TP	transitional phase, changing cushion mass flow rates
Accl	accelerometer

Subscripts

c	cushion
e	ejector
fp	fan primary
t	trunk

SECTION I

INTRODUCTION

1. BACKGROUND

The Air Force Flight Dynamics Laboratory is currently conducting a joint project with the government of Australia to equip an Australian drone, the Jindivik, with an Air Cushion Landing System (ACLS). To accomplish this task, two separate air cushion trunks are being used. The Air Cushion Take-Off System (ACTS) uses a trunk which is dropped off after take-off. The Air Cushion Recovery System (ACRS) uses a trunk which is streamlined along the bottom of the fuselage during flight and inflated just prior to landing. Initial testing performed with Jindivik ACRS trunk revealed that trunk oscillations, referred to in this report as "flutter," were evident in the taxi mode. Therefore, this technical document reports on an experimental investigation of trunk flutter and some attempts to eliminate its occurrence.

All the experimental testing was initially planned to be performed on a two-dimensional (2-D) full-scale section of the trunk used during the take-off of the Jindivik; however, it was shortly discovered that the section of the ACTS trunk used in the setup would not flutter. Later, installation of the actual ACTS trunk onto the Jindivik confirmed the finding that the ACTS trunk would not flutter. Therefore, it was decided to perform some flutter investigations on the three-dimensional (3-D) full-scale landing system, as shown in Figure 1.

Earlier tests of the ACRS trunk demonstrated its fluttering tendency; however, this trunk was scheduled for Australian flight tests within two months. With this time restraint, the Jindivik was quickly instrumented and equipped with ACRS trunk for testing. Four areas believed to have a possible effect on trunk flutter were investigated. These were:

(a) increased trunk pressure (P_t)

(b) variations of cushion mass flow ($\dot{m}_c$)

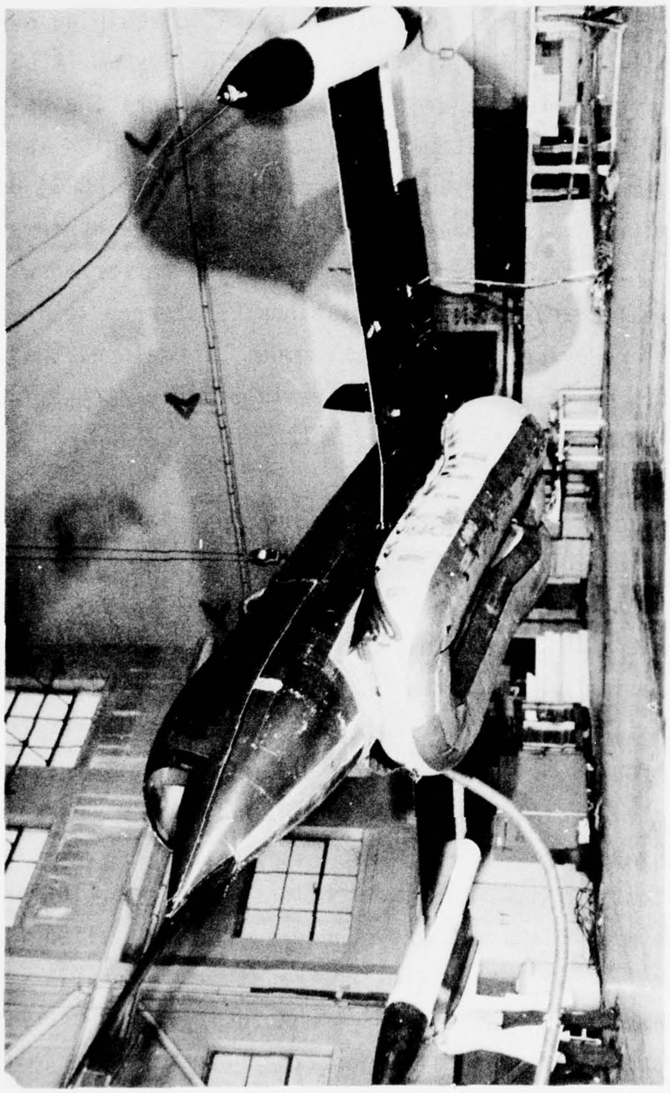


Figure 1. ACRS Trunk on the Jindivik

(c) a tape restraint system

(d) weights attached to the trunk

None of the above methods proved satisfactory

With the knowledge gained from the three-dimensional tests, the decision was made to redesign the two-dimensional test setup shown in Figure 2. The new test setup was adapted with a cushion air flow channel and the trunk tread holes were blocked. This resulted in the trunk section exhibiting flow characteristics similar to those of the ACRS system. Flutter was then obtained when a sufficient amount of cushion mass flow was provided. The following attempts to reduce trunk flutter were investigated on the two-dimensional setup: floor strips, tread strips, tread pucks (short tread strips), trunk stiffening tube, and an air flow deflecting strake. The first three methods of the above attempts were successful.

2. RELATED EFFORTS

Several experimental tests involving the investigation of trunk flutter have been undertaken during the past few years. Four studies which have significant findings are noted in the reports written by the Canadian Government, Bell Aerospace Company, Boeing Company, and Southwest Research Institute. The above reports are listed as References 1, 2, 3, and 4, respectively. A brief summary of the conclusions of these reports, in the order of their publishing date, is given below.

The Canadian report was written by H. S. Fowler, dated November 1971, and is entitled "A Method of Controlling "Skirt-Buzz" in Light Air Cushion Vehicles with Peripheral-Bag Skirts." In this report, weights known as "Buzz-Dingers," were found to eliminate the skirt flutter. The trunk or peripheral-bag skirt was made of a 0.0035 in. transparent plastic membrane. A theoretical analysis of the flutter phenomenon was performed. Calculated frequencies were similar to those measured experimentally through a two-dimensional test setup. The formula used is provided below (Reference 1).

$$N = \frac{n}{2L}\sqrt{\frac{F}{m}\ g_o}$$

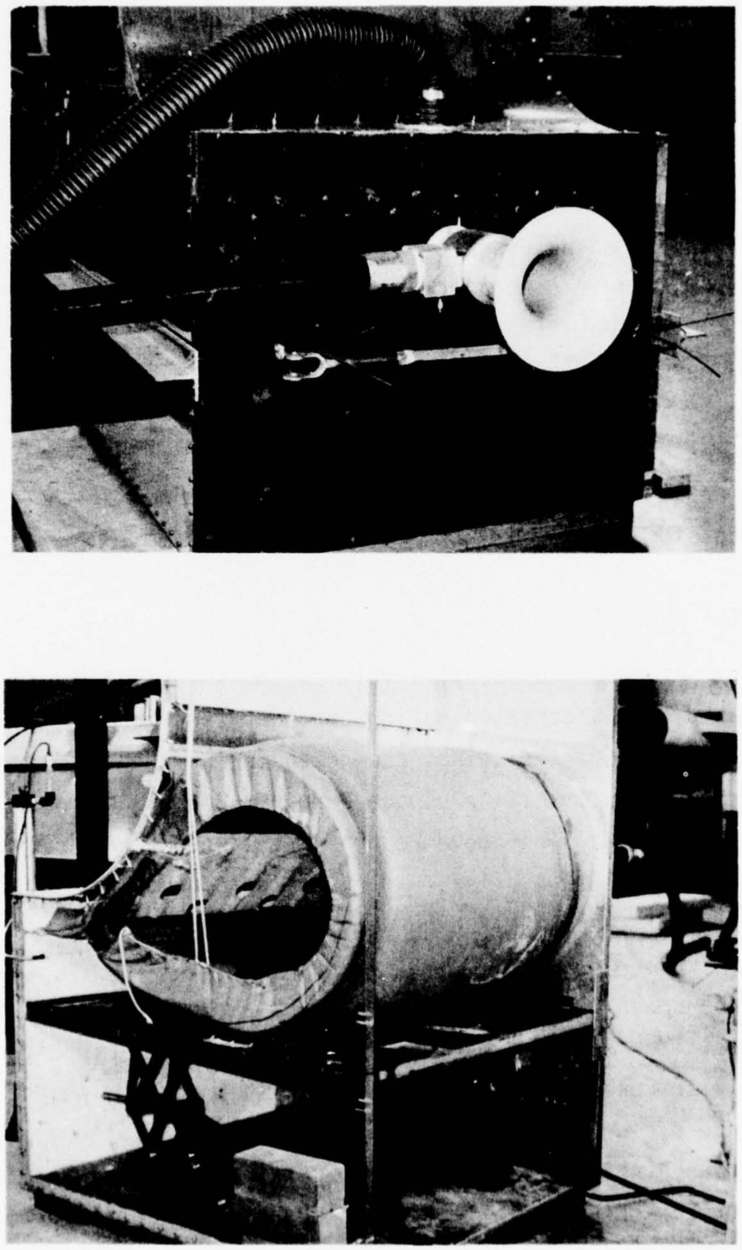


Figure 2. 2-D Test Setup

where:

N = Frequency - Hz (cps)

L = Length - ft

F = Tensile force in string - lbf

m = Wt. per unit length of string - lbm/ft

g_o = 32.2 (lbm x ft)/lbf x sec^2)

n = Vibration order (1,2,3, etc.)

The major conclusions of the Bell Aerospace Company report, written by J. M. Ryken, dated 25 August 1972, and entitled "Experimental Investigation of Air Cushion Landing System (ACLS) Trunk Oscillations," are listed below (Reference 2).

(a) "For a given trunk configuration, the stability boundary is approximated by a line of constant P_c/P_t on a plot of P_t vs P_c. (Higher values of P_c/P_t are unstable.)"

(b) "For a given trunk and cushion pressure, an increase in cushion flow (and hence an increase in the gap under the trunk) decreases stability."

(c) "A strake attached to the bottom of the trunk outboard at the ground tangent is very effective in stopping trunk oscillations or in extending the stability region to higher P_c/P_t ratios and/or to cushion flows considerably higher than those for which stable operation is possible without a strake." The two-dimensional tests performed by Bell had a maximum trunk pressure of only 10 inches of water versus the maximum pressure of 49.8 inches of water or 1.8 psig used to pressurize the Jindivik's trunks.

On pages 25 and 26 of the Boeing report (Reference 3), written by L. H. Gardner, dated 20 March 1973, and entitled "A-4 Twin Pod Air Cushion

Test Specimen," the following results of tests involving trunk side wall flutter are discussed:

"In initial tests, it was found that to eliminate this flutter it was necessary to restrict fan inlet substantially, thereby reducing trunk pressure. Opening trim holes and allowing air flow to enter the cushion cavity and then flow out between the trunk and the floor usually increased the flutter. Moving the test specimen onto a slotted floor greatly reduced this flutter but ground friction increased several times. Apparently side wall flutter is causing the trunk to beat against the floor. Taping the inner and outer rows of peripheral holes seemed to have no effect. Likewise, adding a chine (a deflector for air escaping from beneath the trunk, also called a strake) "just above the outer row of holes to deflect the upward flow of air showed little or no effect." Like the test data contained in this report on the Jindivik, Gardner used maximum trunk pressures in the 1.8 psig region.

The Southwest Research Institute report, written by R. L. Bass, dated June 1973, and entitled "An Experimental Study of Skirt Flutter on Surface Effect Take-Off and Landing (SETOL) Craft" has the following conclusions listed (Reference 4):

(a) "Skirt flutter is initiated when the velocity in the gap between the skirt and the ground reaches a sufficient magnitude. Bag height and cushion pressure affect flutter only as they affect jet velocity" of the air escaping out from beneath the trunk.

(b) "Flutter threshold velocity varies with bag pressure, bag geometry, bag flow, and the surface over which the bag is placed."

(c) "Flutter frequencies increase with bag pressure or jet velocity" of the escaping air.

(d) "Flutter amplitudes increase with decreasing bag pressure and/or increasing jet velocity. Flow through the bag decreases flutter amplitude."

(e) "The critical region of velocity and static pressure change, which leads to flutter, occurs in a narrow region ($\pm 10°$) from the bag gap."

(f) "During flutter cycle, the bag strikes the ground near the bottom tangency point and an axial traveling wave moves circumferentially around the bag surface."

The Southwest Research Institute report is predominantly frequency oriented, and there are only a few measurements of flutter amplitude. As stated by Bass (Reference 4), "the displacement magnitudes could not be obtained over most of the test conditions since the oscillation amplitude exceeded the measurement range." Maximum trunk pressures used in Bass's report were around 24 inches of water or 0.86 psig. These pressures are less than half the trunk pressures used in the Jindivik tests.

The objective of the tests reported in this investigation on the Jindivik is the same as those of the above reports, that is, the elimination of trunk flutter.

SECTION II

EXPERIMENTAL FACILITIES

1. TWO-DIMENSIONAL TEST FACILITY

It was initially decided that this flutter investigation would be performed on the two-dimensional test setup which was modeled after the Air Cushion Take-Off System (ACTS), as shown in Figure 3. Under those flow conditions, however, the trunk would not flutter. To induce flutter, the test setup was redesigned and modeled after the Air Cushion Recovery System (ACRS) which had exhibited flutter in earlier tests (Reference 5).

The methods of air input are the major differences between the two setups. The ejector was the only source of air for the initial 2-D design, as shown in Figure 3. In this initial design, air was forced into the trunk and then out of the tread nozzles. The escaping air then entered the cushion cavity and established the required cushion pressure (P_c). In the redesigned test setup (Figure 4), the ejector was replaced with a direct bleed air line and the ejector was mounted on the side of the test box. This redesigned system maintained the trunk flow which was needed to inflate the trunk, while the ejector provided a direct source of air flow into the cushion cavity.

The minor changes between the two 2-D designs included the addition of floor pressure taps, a nailed down floor, and blocked trunk tread nozzles to the redesigned 2-D system. The floor was nailed down because the flutter obtained with the redesigned test setup was too violent and caused the floor supported by jacks to bounce. The trunk tread nozzles were blocked because the limited air supply system was depleted too rapidly through the 1/4-in. nozzle holes. Since the landing (ACRS) trunk had fewer and smaller nozzles than the take-off trunk (see Figure 5), the blocked tread nozzles and subsequent side wall leakage were considered a good representation of the ACRS system.

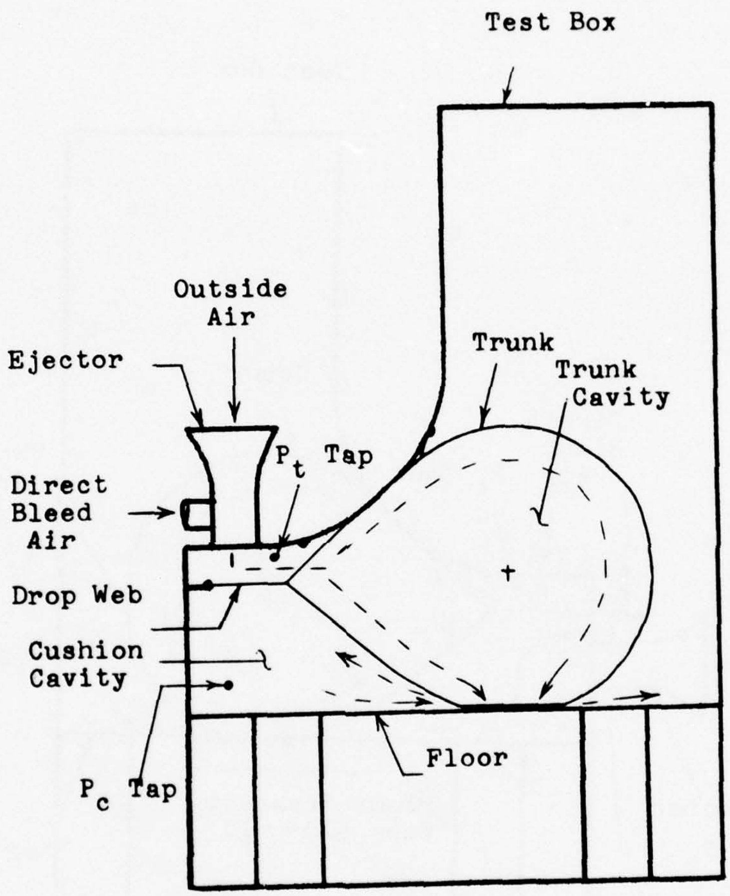


Figure 3. 2-D Test Setup, ACTS Configuration

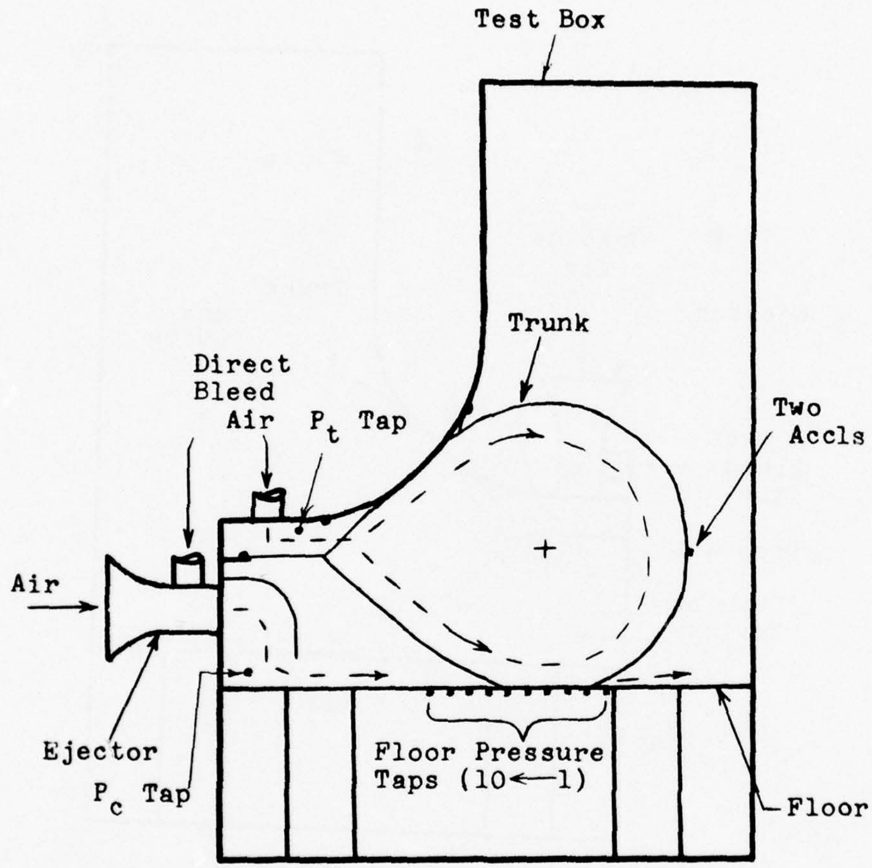
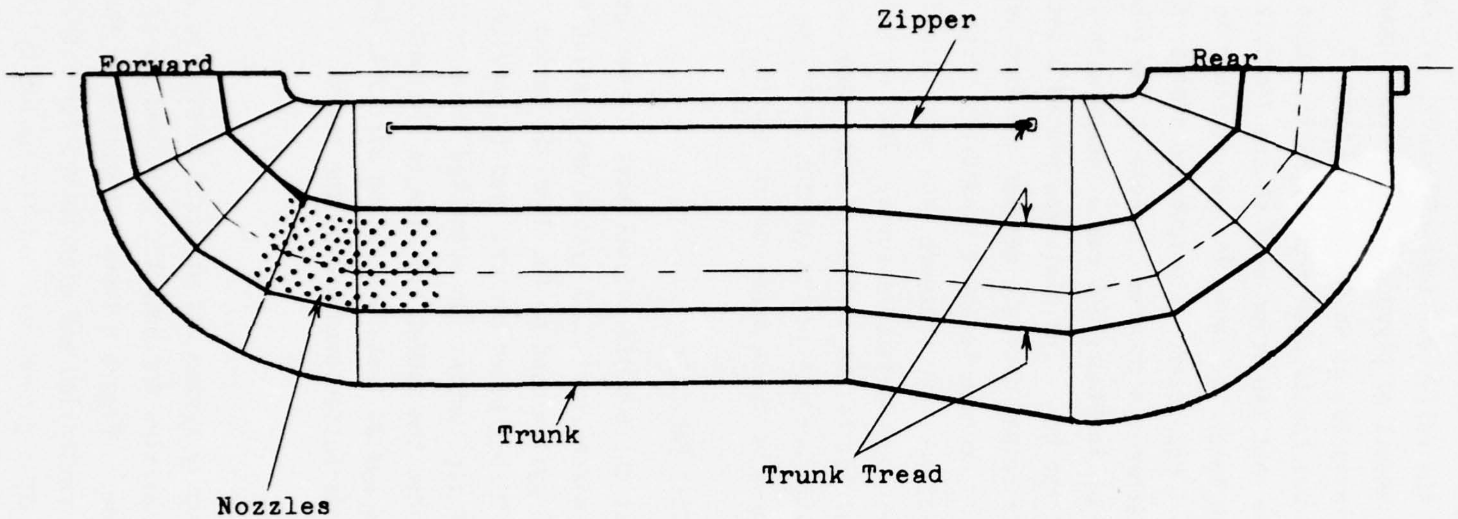


Figure 4. 2-D Test Setup, ACRS Configuration



ACRS Nozzles:

On the forward third of the tread, 0.125 inch diameter, perpendicular to the surface. 394 places, staggered in concentric rows.

ACTS Nozzles:

On the entire trunk tread, 0.25 inch diameter, angled inward at 45° to surface. 196 holes in each row; 9 rows.

Figure 5. The ACRS and ACTS Trunk Tread Nozzles

The test box of the 2-D test setup was designed to accommodate a 32-inch wide section of the full-scale take-off trunk. It was constructed largely of 1-inch thick sheets of plywood. One of the sidewalls was a 1-inch thick sheet of Plexiglas, as was shown in Figure 2. The curved backing of the test box was constructed from 0.125 in. sheet of aluminum and was designed to represent the lower half of the Jindivik's fuselage. The trunk girt, as shown later in Figure 14, was attached to this simulated fuselage with a bead clamp at a location similar to where the actual Velcro trunk attachment mechanism connects to the fuselage. The trunk drop web, also shown in Figure 14, was attached with a bead clamp to a metal plate inside the box. The plate was placed 3 inches below the fuselage to simulate the actual distance between the drop web and the fuselage. The ground was represented by a stationary floor situated 13 inches below the fuselage. Ten pressure taps were placed in the floor for recording the floor static pressures. They were numbered 1 through 10, from the outside to the inside. Another pressure tap was placed in the trunk cavity and one in the cushion cavity to permit the recording of the pressures in those areas during testing.

2. THREE-DIMENSIONAL TEST FACILITY

During the time that the two-dimensional test box was being redesigned, the three-dimensional ACRS system was available for testing. A schematic of the ACRS system used on the Jindivik during these tests is shown in Figure 6. Direct bleed air was used to provide the air flow into the trunk. A tip turbine fan augmented the direct bleed air that drove it and provided the needed air flow to the cushion cavity. Figure 1 shows the ACRS system installed on the Jindivik, while Figure 7 presents the weight distribution used during the tests.

3. AIR SUPPLY SYSTEM

A compressed air supply system was utilized to provide air flow to the trunk and cushion cavities for both the two-dimensional and three-dimensional test programs. Figure 8 shows schematically the method in which the air flow was controlled and distributed for both tests. Prior to all tests, the Type MD-1 ground cart had its twelve cylindrical bottles

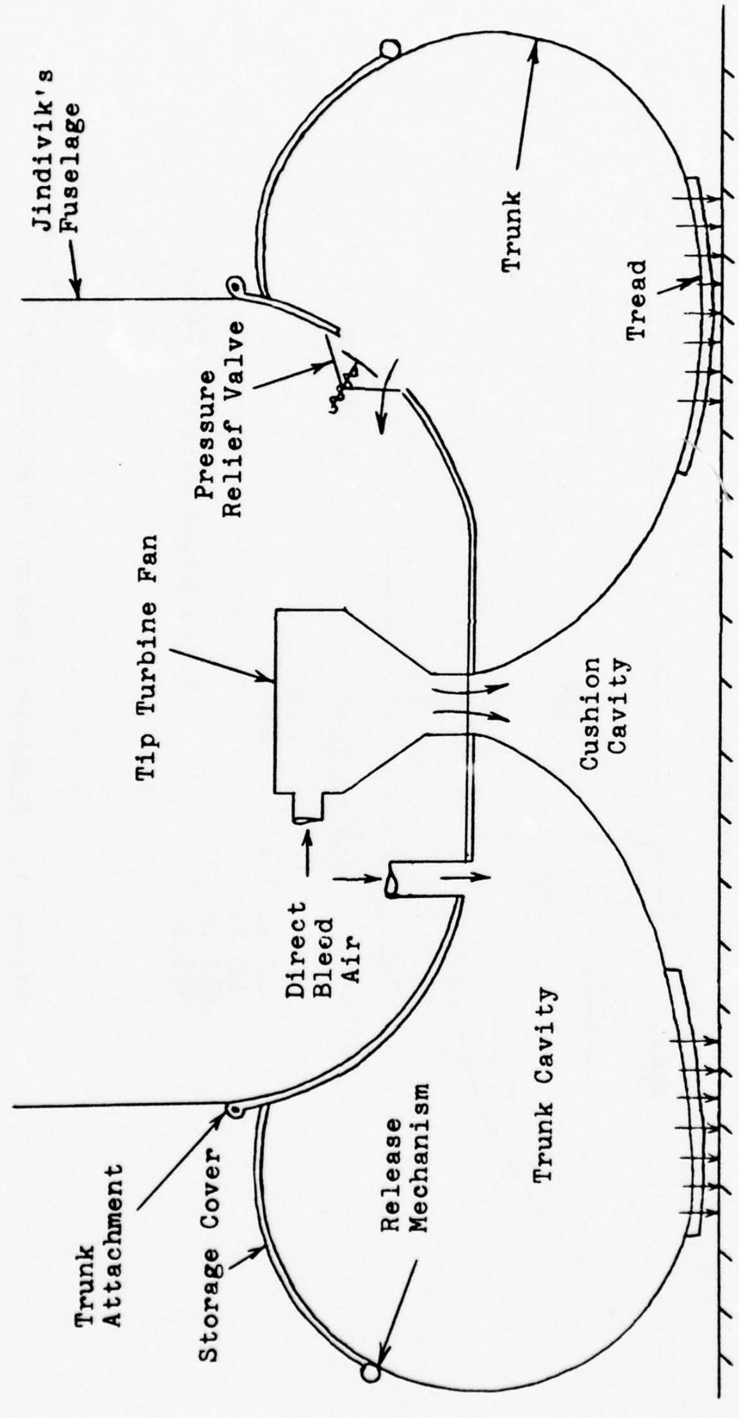


Figure 6. Schematic of the 3-D ACRS System

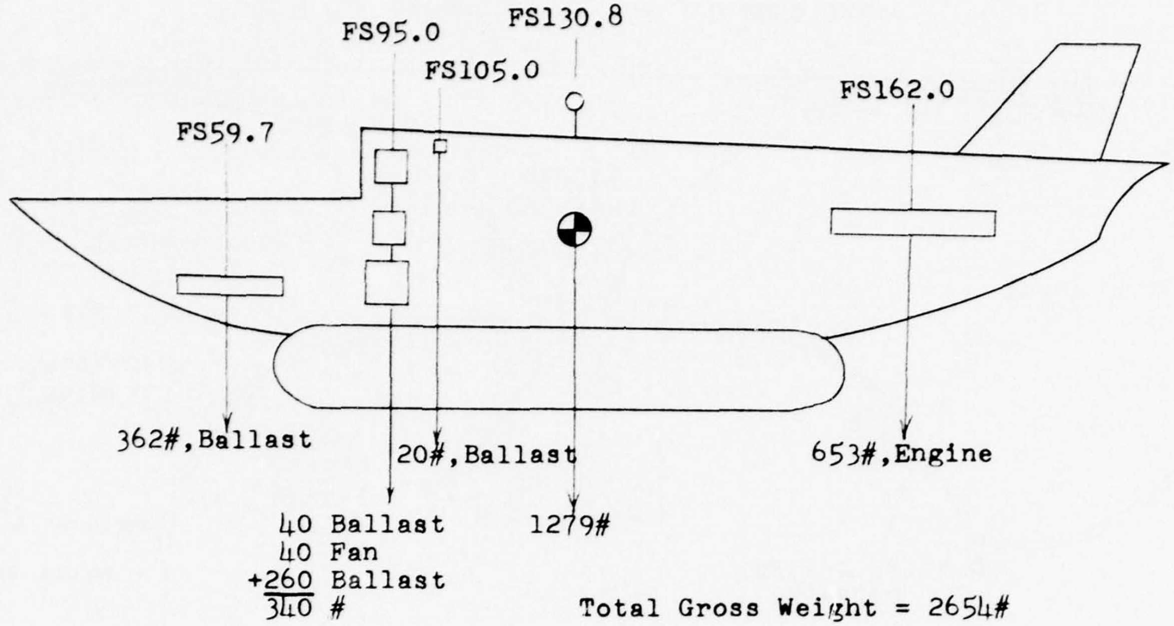


Figure 7. Jindivik's Weight Distribution

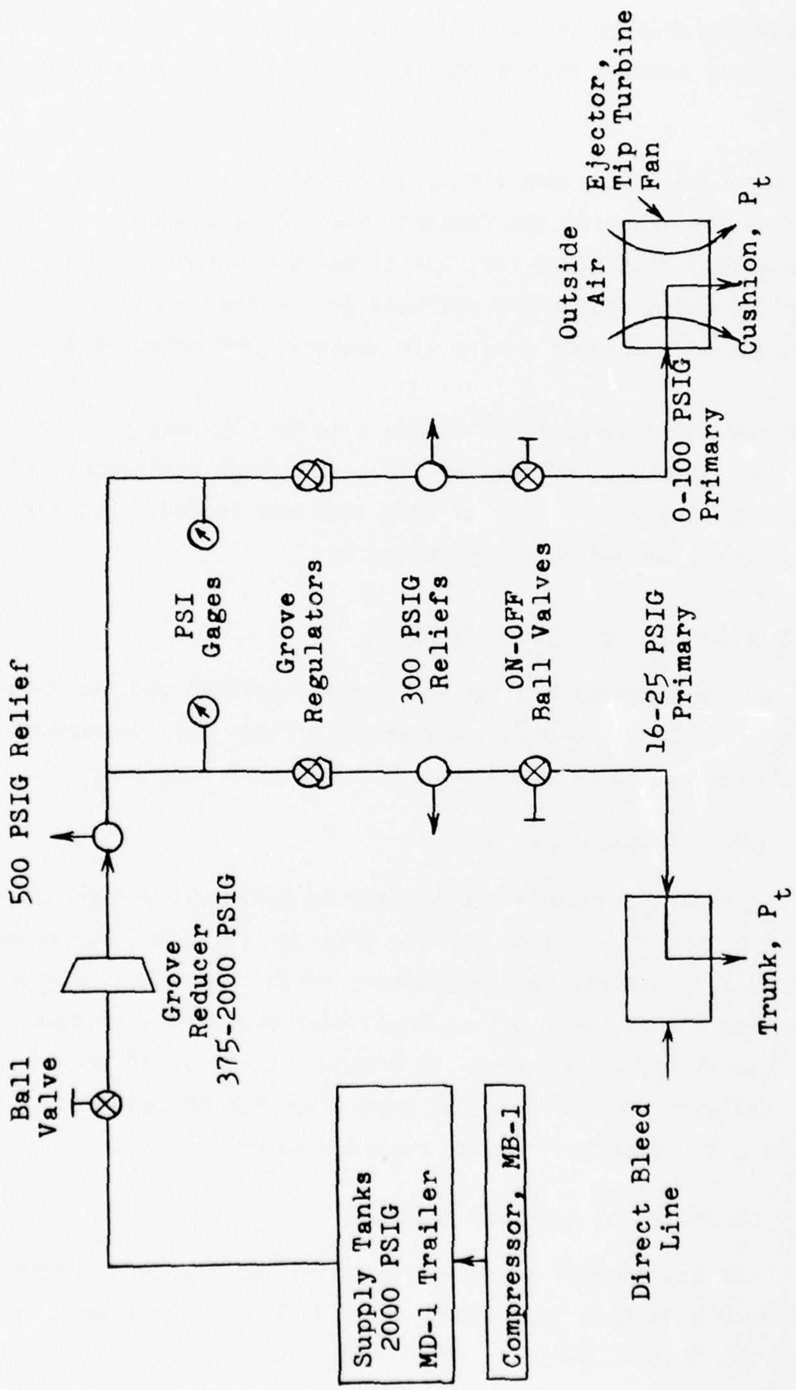


Figure 8. Air Supply System

pressurized to 2000 psig. After a typical run of two minutes, the supply pressure would drop to below 1000 psig. A two-hour charging of the compressed air bottles with a mobile air compressor was required between most tests.

In the case of the two-dimensional tests, direct bleed air was provided to the trunk at the required air flow and pressure. The cushion flow was also direct bleed air, but it was augmented with an ejector. The ejector, was a simple and reliable device that reduced the bleed air requirements by providing a mass air augmentation ratio of three-to-one.

For the three-dimensional tests, cushion flow was provided by a tip turbine fan. The tip turbine fan had a very high performance ratio which provided the high volume rate of flow that was needed. The air flow to the trunk was provided by direct bleed air.

4. INSTRUMENTATION AND DATA RECORDING

The recorded parameters for the two-dimensional and three-dimensional tests were similar, and unless otherwise stated, the instrumentation and recorded data listed below were included in both programs.

a. Pressure Readings

Pressure transducers were used to measure trunk pressure (P_t), cushion pressure (P_c), ejector drive pressure (P_e), and fan primary drive pressure (P_{fp}). In the two-dimensional tests, the floor pressure distribution was measured with a Scanivalve pressure transducer which had the capability of measuring 48 pressure ports in 20 seconds. Some of the available Scanivalve ports were also used to record P_t and P_c values as a check on the regular recorded values.

b. Recording of Pressure Readings

The instruments used for recording the pressure readings were a Bell and Howell data tape (Model VR 3700B) and a Honeywell visicorder oscillograph (Model 906A), as shown in Figure 9.

Figure 9. Pressure Recording Instrumentation

c. Flutter Data

The flutter data were recorded and analyzed by personnel from the vibration analysis branch of the Air Force Flight Dynamics Laboratory (AFFDL). The data were conditioned by automatic gain controlled (AGC) amplifiers and recorded on a tape recorder. Timecode was provided by a timecode generator. A detailed presentation of all the flutter data will be available in a report which will be written by the vibration analysis branch. A photograph of the frequency recording equipment used during the tests is shown in Figure 10.

The vibration data which were used to obtain frequencies, acceleration forces, and amplitudes of the flutter, were obtained from very small crystal accelerometers. They were about the size of a pencil eraser. For the three-dimensional tests, seven accelerometers were glued to the left side of the trunk. Two of the seven were placed on the inner surface of the trunk and the remainder were placed on the outer surface, as shown in Figure 11. The trunk used in the two-dimensional tests had two accelerometers glued to it as shown in Fiaure 4.

d. Cushion Mass Flow Rates

For the two-dimensional tests, cushion flow ($\dot{m}_c$) was estimated by recording the ejector drive and cushion pressures and utilizing Figure 5 of Reference 6. This figure presents lines of constant ejector drive pressure on a graph of cushion pressure versus cushion mass flow rate (see Figure 12 of this report).

The three-dimensional cushion mass flow rates were calculated with the values of the primary fan drive pressures and with the aid of an actual flow curve for the tip turbine fan. This flow curve was plotted on a graph of output mass flow versus fan primary drive pressure and was developed by Major J. Vaughan of the AFFDL (see Figure 13).

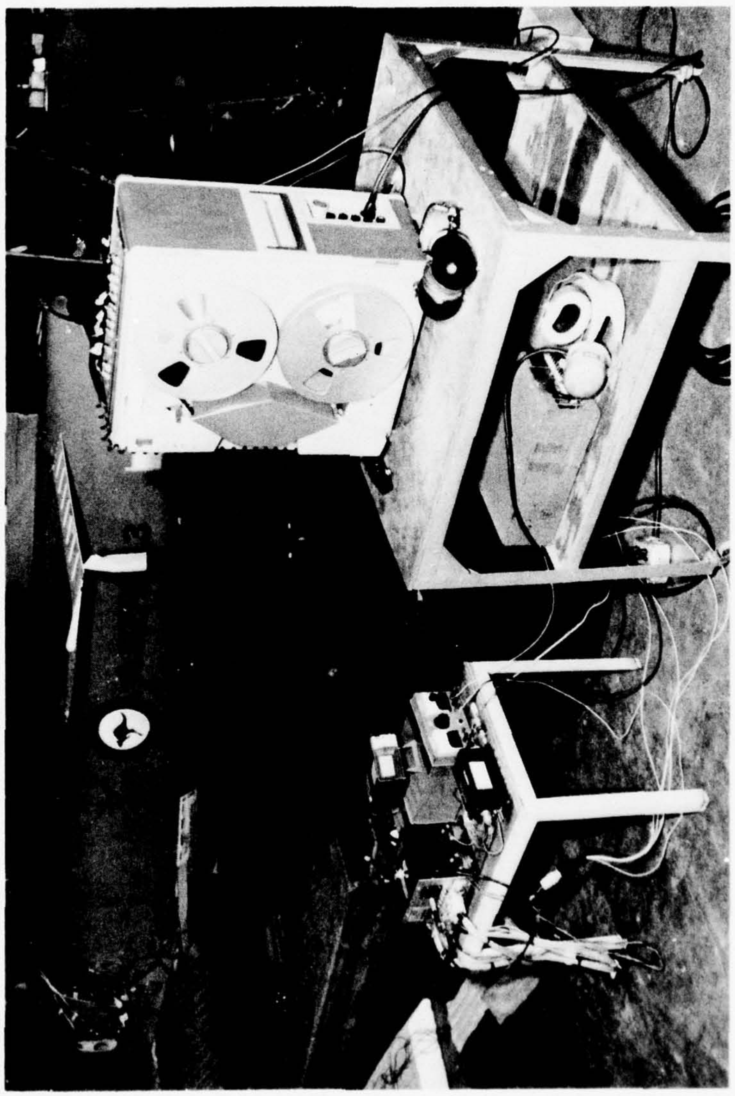


Figure 10. Frequency Recording Instrumentation

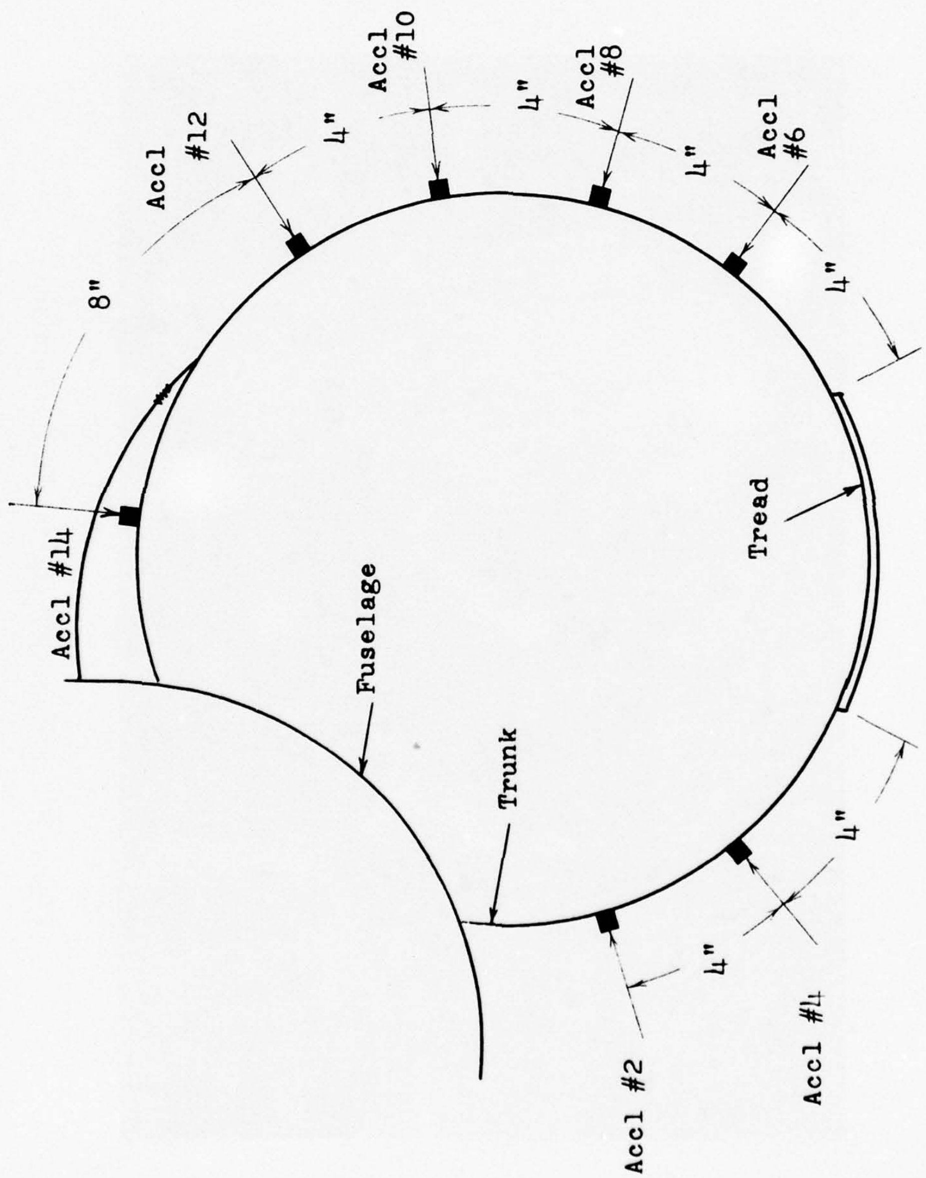


Figure 11. Accelerometer Locations on the 3-D Trunk

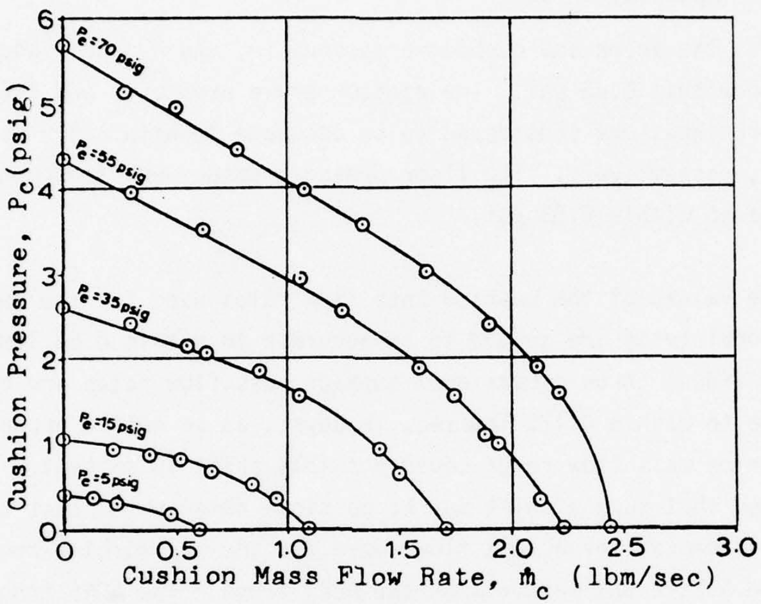


Figure 12. Total Mass Flow Rate into Cushion Cavity as a Function of Back Pressure for Various Ejector Drive Pressures

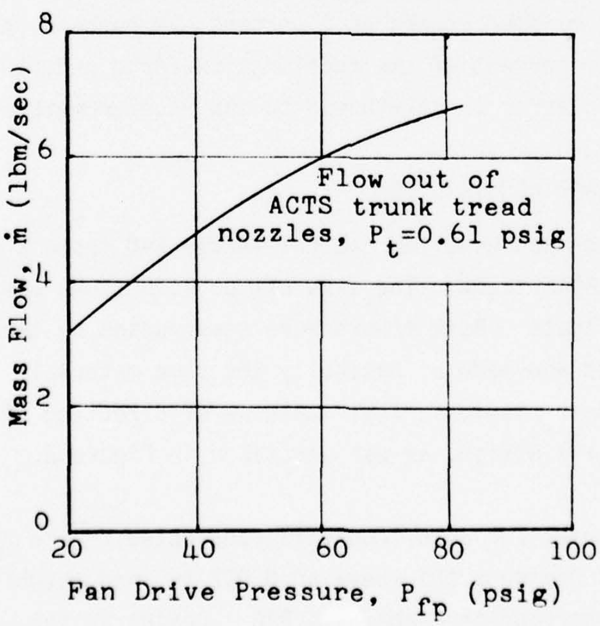


Figure 13. Actual Flow Rate for the Tip Turbine Fan

e. Accuracy of Data

The trunk and cushion pressures (P_t and P_c) are judged to be accurate within 0.05 psi. The ejector drive pressures and fan primary drive pressures are considered to be accurate to within 0.5 psi and 1.0 psi, respectively. The floor pressure values are judged to be accurate to within 0.05 psi.

The values of the cushion mass flow rates used for the two-dimensional tests are judged to be accurate to within 0.06 lbm/sec. The individual three-dimensional cushion mass flow rates are considered accurate to within 0.125 lbm/sec. However, as an entire group, the 3-D cushion mass flow rates could possibly shift 10 percent. It was estimated that such a shift may be possible because the test that was run to determine the actual flow curve for the tip turbine fan (Figure 13) used the ACTS trunk rather than the ACRS trunk. The ACRS trunk was used on the three-dimensional tests.

The trunk frequencies, acceleration forces, and flutter amplitudes were judged to have maximum errors of 1 percent, 10 percent, and 10 percent, respectively. Fifty percent of the acceleration force and flutter amplitude worst case error is attributed to the accelerometers.

5. TRUNK MATERIAL AND CONSTRUCTION

The landing trunk was used for the full-scale 3-D tests and is referred to as the ACRS trunk. The take-off or ACTS trunk was used for the full-scale 2-D tests. Both trunks were constructed by the B. F. Goodrich Company and are made of basically the same material. They differ mainly in their missions, their methods of directing air flow, and their tread nozzle design, as was described in Figure 5.

The basic material for both trunks is fabricated from a neoprene-coated nylon fabric having a thickness of 0.022 in. and weighing 15 oz/yd^2. The denier of one chord of the fabric is 840. Denier is the weight in grams of 9000 meters of chord length. The minimum strength of the

uncoated fabric is 625 lb/in. The chord material is nylon 6/6 and weighs 7.3 oz/yd^2. There are approximately 30 yarns per inch in both directions. The trunk tread is made from tire tread rubber that is 3/8 in. thick.

Figure 14 shows a sketch of the 32-inch wide section of the full-scale ACTS trunk that was used in the two-dimensional tests. The full-scale ACRS landing trunk used for the 3-D tests was shown in Figure 1.

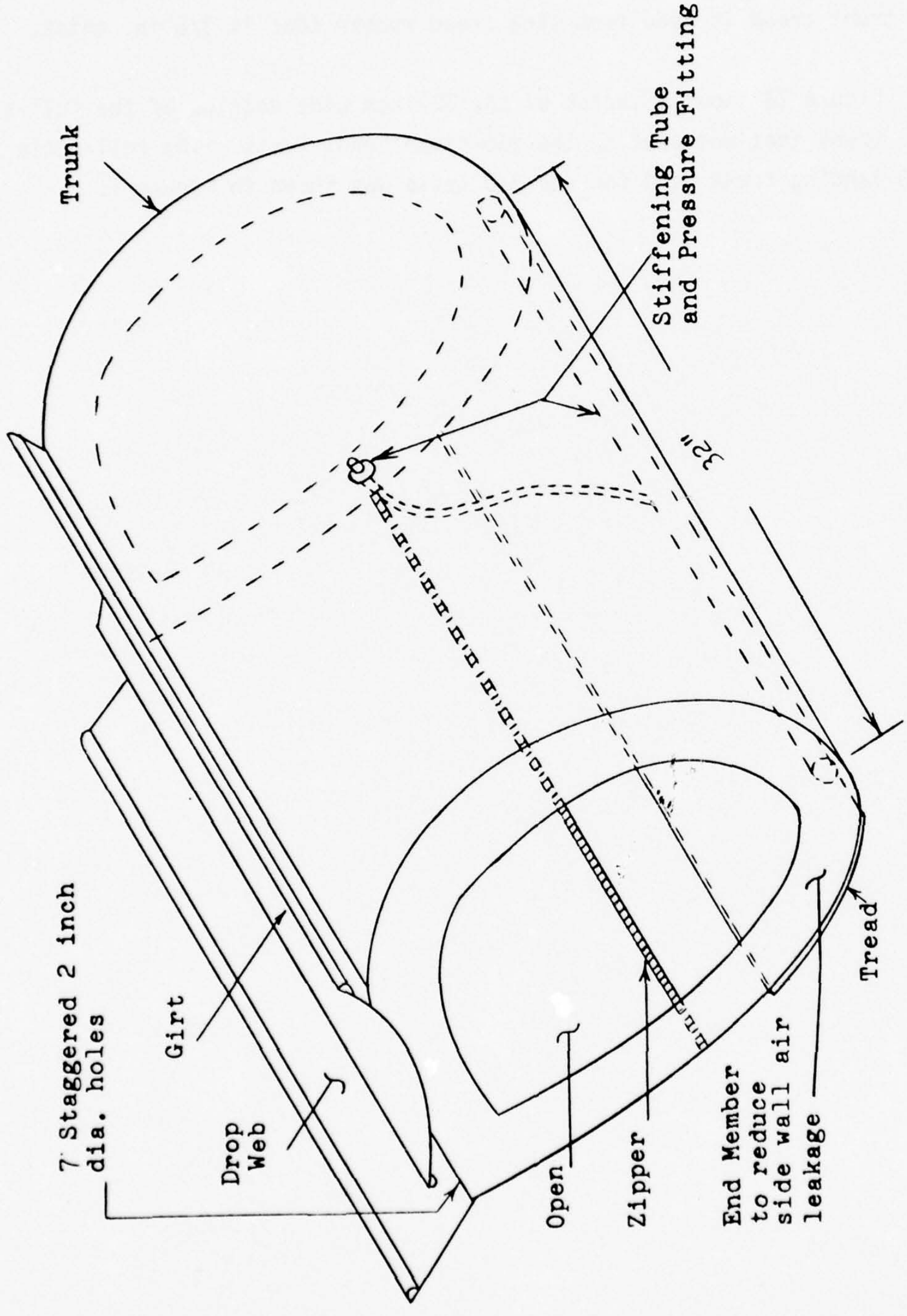


Figure 14. 2-D Trunk Test Section

SECTION III

TEST PROCEDURE

The test program consisted of 61 runs performed over a two month period. There were 20 three-dimensional tests and the remainder were two-dimensional tests. Table 1 lists the tests and the trunk configurations which were used. This table is divided into three columns. The first column lists the configuration of the trunk during the tests. The second and third columns list the two-dimensional and three-dimensional test numbers, respectively. These tests numbers correspond to items listed under the trunk test configuration column. As noted in the table, tests P1 through P7 and tests 47 through 54 were preliminary tests which had no vibration recording equipment in operation. Those test numbers which are underlined are discussed in this report.

Prior to the start of each test, a checklist was followed to lessen the possibility of errors. With all required instrumentation on, the tests began with the opening of the trunk pressure line valve. Once the trunk was pressurized, the cushion pressure line valve was opened to provide air to drive either the ejector or the tip turbine fan. During most tests, the trunk pressure was maintained constant while the cushion drive pressure, and therefore the cushion mass flow rate, was increased in definite increments. At each new cushion mass flow rate all test parameters were held constant so that an accurate vibration analysis of that section could be taken. Cushion drive pressure was usually increased until flutter was obtained or until it was apparent that the trunk would not flutter under normal air flow conditions. Test runs were usually between one and two minutes long.

TABLE 1

TEST MATRIX

Trunk Test Configuration	Two-Dimensional Tests	Three-Dimensional Tests
Clean	P1*, P2*, P3*, P4*, P6*, P7*, 1, 2, 9, 10, 33, 34, 35	P47*, P48*, P49*, P50*, P51*, P52*, P53*, P54*, 55-1, 56-2, 57-3, 66-12
Weights		58-4, 59-5, 60-6
Tape		61-7, 62-8, 63-9 64-10, 65-11
Strake	23, 27	
Stiffening Tube	P5*, 24	
Increased P_t	34, 35	57-3, 60-6, 62-8 63-9, 64-10, 66-12
Floor Strips	3, 4, 5, 6, 7, 8	
Tread Strips	11, 12, 13, 14, 15 16, 17, 18, 19, 30 31	
Tread Pucks	20, 21, 22, 25, 26, 28, 29, 32	

Note: Results from the underlined tests are used in this report

* Preliminary tests, no vibration data taken

SECTION IV

TEST RESULTS

1. FLUTTER INVESTIGATION

It was determined from the initial tests performed on the ACTS modeled 2-D test setup that trunk air flow alone would not produce flutter; therefore, cushion air flow was introduced in the ACRS 2-D test setup and flutter was easily attained. The first tests performed in the following two-dimensional and three-dimensional programs were tested with clean trunks in order to establish a baseline for the study of trunk flutter. The word "clean" refers to the trunk in its normal state without attachments.

In the following discussions of test results, all test numbers which have two numbers separated by a dash, like 57-3, represent three-dimensional tests. Singular test numbers, like 10, represent two-dimensional tests. The flutter amplitudes measured for the 2-D and 3-D tests were measured at the accelerometer locations shown in Figures 4 and 11, respectively, unless otherwise specified.

Figures 15 and 16 present test flutter amplitudes as a function of mass flow rates, for two-dimensional and three-dimensional clean tests, respectively. The results show that at a given trunk pressure, increasing the cushion mass flow rate increases the flutter amplitudes. Similar results were also noted in the conclusions of References 2, 3, and 4.

A noticeable difference in flutter amplitudes is noted when a comparison of Figures 15 and 16 is made. Figure 15, representing the 2-D test, has an amplitude of around 1.5 inches at 0.85 lbm/sec, while the amplitude of the 3-D test is only 0.8 in. at a mass flow rate of 6.8 lbm/sec. In attempting to understand this difference in flutter amplitudes between the 2-D and 3-D tests, the apparent answer seems to be the different mass flow rates. However, the mass flow rate of the 2-D test is approximately 1/8 the value of the 3-D test. Since the

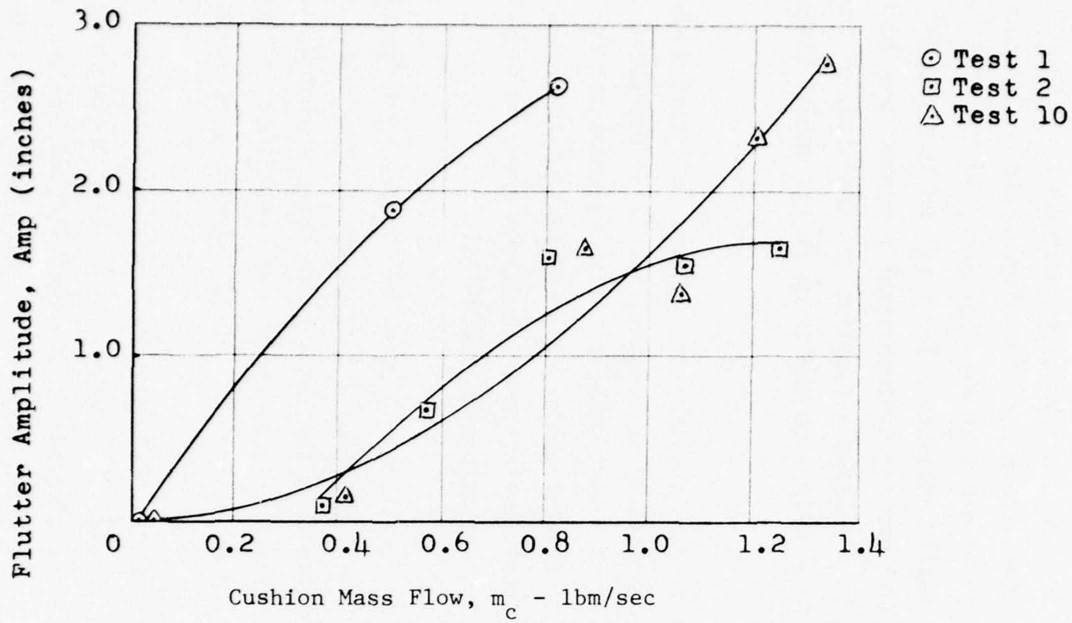


Figure 15. 2-D Clean Trunk Tests, Flutter Amplitudes vs Cushion Mass Flows

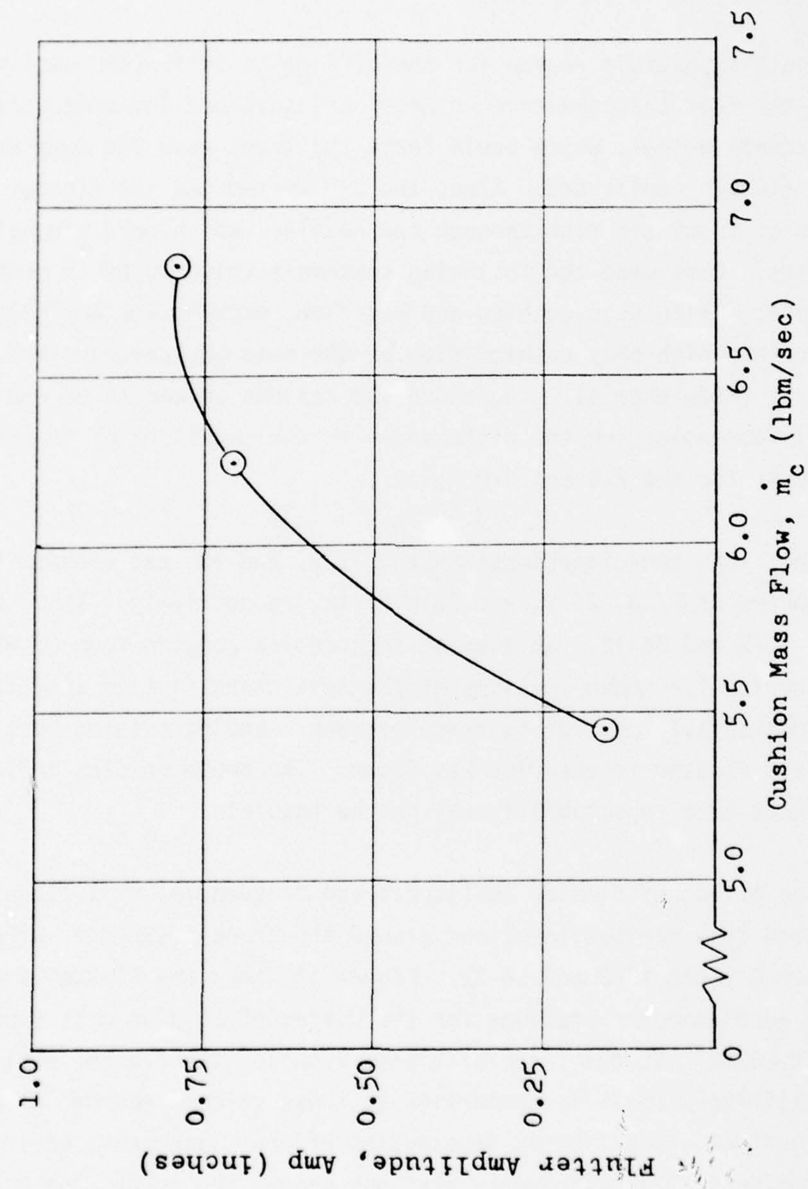


Figure 16. 3-D Clean Test 66-12, Flutter Amplitudes vs Cushion Mass Flows, Accl #10 Only

32-inch trunk section used during the 2-D test is 1/8 the length of the trunk used on the 3-D test, the mass flow rates appear to be of the correct proportions, and therefore are probably not the cause for the large difference in amplitudes.

Another possible reason for the difference in flutter amplitudes may be the fact that the three-dimensional test had the added effect of the aircraft weight, which could force the trunk down and damp out some of the flutter amplitudes. Also, the 3-D system had the flutter reducing effects of trunk air flow through the nozzles, which were blocked for the 2-D tests. Bass made the following statement which tends to support this last idea: "With both cushion and bag flow, oscillation amplitudes are smaller than with only cushion flow at the same bag pressure and jet velocity" (Reference 4). The above two reasons appear to be the most logical for explaining the differences in the magnitude of the flutter amplitudes for the 2-D and 3-D tests.

The clean two-dimensional tests, 1, 2, and 10, had average flutter frequencies of 27.8, 20.8, and 26.0 hertz, respectively. The 3-D clean tests, 57-3 and 66-12, had flutter frequencies ranging from 25.45 to 27.99 hertz, for those portions of the test where flutter amplitudes were substantial. No relationship between changing cushion mass flow rates and flutter frequencies was found. The above results indicate that exact test repeatability may not be possible.

The extent of flutter amplitudes and frequencies of a clean trunk, as viewed from various locations around the trunk's surface, were analyzed in the 3-D tests 57-3 and 66-12. Figure 17 shows the flutter amplitudes versus accelerometer stations for the different cushion mass flow rates of test 66-12. At the inner stations, 2 and 4, the flutter amplitudes were relatively small in comparison to those values recorded along the outer surface. The flutter frequencies of the clean test, 66-12, were the same for all accelerometer stations around the trunk when a constant mass flow rate was maintained.

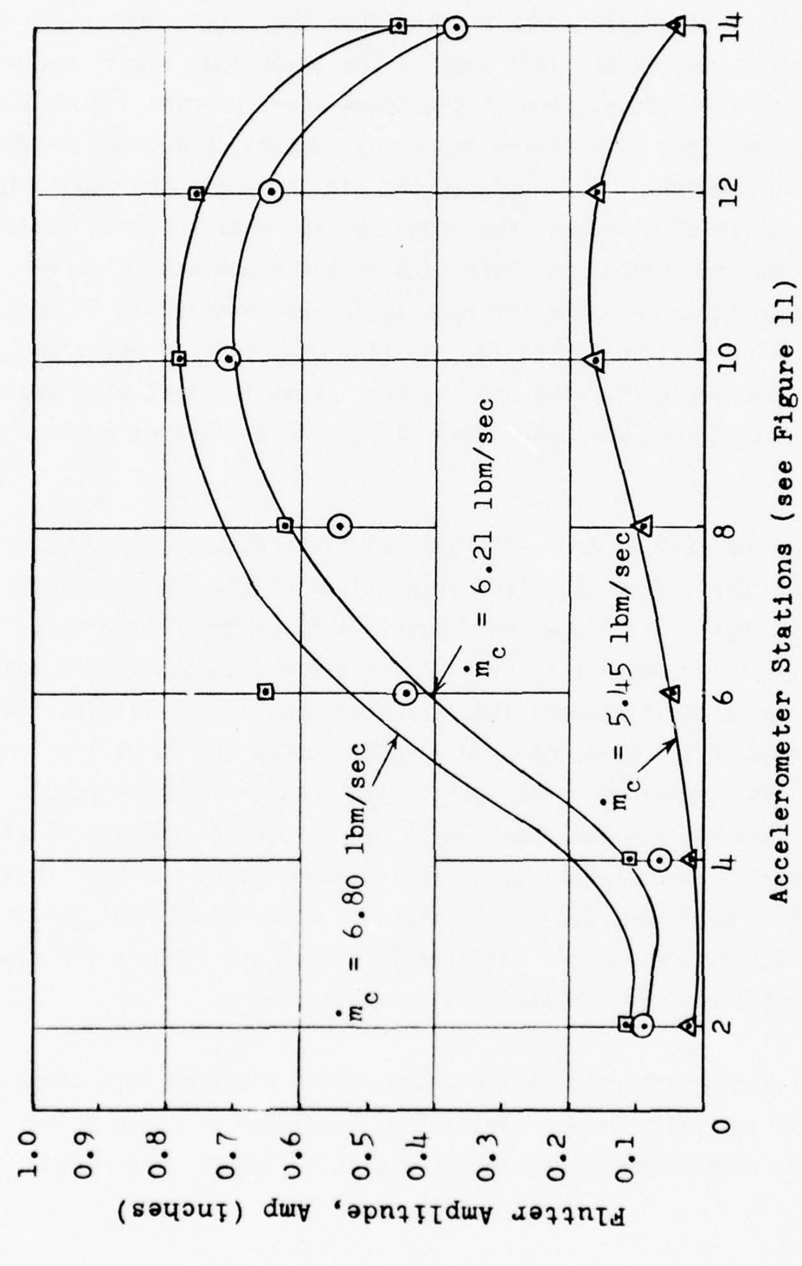


Figure 17. 3-D Clean Tests 66-12, Lines of Varying Mass Flows

The effect of aircraft roll on flutter was also investigated in some of the 3-D tests. Figure 18 addresses this topic and contains data which supports the idea that increasing cushion flow increases flutter amplitude. It is important to recall at this point that the accelerometers on the 3-D tests were only on the left side of the trunk and, therefore, only the events of the left surface of the trunk were recorded. With the right wing down, the right side of the trunk was supporting a large amount of the Jindivik's weight. This reduced the air gap under the right side of the trunk, which also reduced the amount of air escaping from beneath it. While this was occurring, the left side of the trunk was relatively free from any weight, and cushion air readily escaped beneath it in large quantities. As seen in Figure 18, the flutter amplitude was greatly increased when the right wing was lowered. When the left wing was lowered, the flutter amplitude was below the values recorded when the wings were level.

During the initial three-dimensional flutter tests, the theory that flutter may result from the blade revolutions of the tip turbine fan was considered. Ryken disallowed this possibility by the following observation: "Although it is possible that fan characteristics could influence trunk oscillations, the fact that similar oscillations have been observed on the LA-4, on several ACLS models and in Bell's large and small two-dimensional test sections (all with different fans) indicates that the fan does not play a major role in trunk oscillations" (Reference 2). This thought is strongly supported by the fact that in the 2-D tests performed herein, flutter was observed without the use of a fan. Instead, the ejector was used to supply the cushion air flow, while direct bleed air was supplied to the trunk.

Several high-speed black and white motion pictures were taken of the 3-D ACRS system while it was fluttering. Analysis of those films did not reveal any interesting observations about the flutter phenomenon.

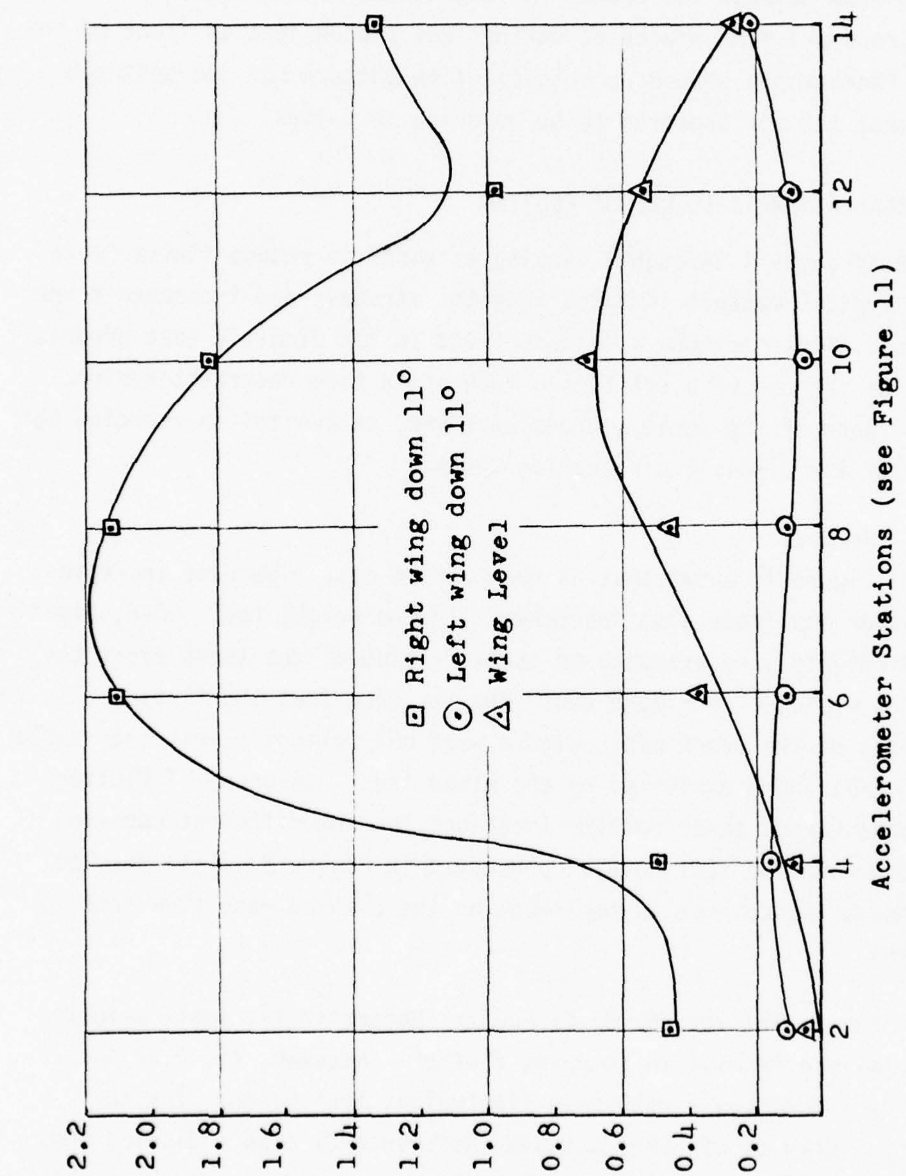


Figure 18. Effect of Aircraft Roll on Flutter Amplitudes, Test 64-10

A still camera with high-speed film was used during the 2-D tests to help analyze the flow pattern characteristics of the air after escaping from beneath the trunk. A large rake, constructed of long thin welding rods and fine pieces of string, was placed just in front of the trunk. Photographs showed no specific flow pattern but the test did reveal that the air appeared to be escaping in pulses.

2. TYPICAL ATTEMPTS TO REDUCE FLUTTER

In References 1 through 4 varying attempts to reduce flutter were tried. Typical methods included weights, strakes, and increased trunk pressures. These methods were also tried in the Jindivik test program, as well as the use of a stiffening tube and a tape restraint system. However, none of the above methods were very successful in reducing the flutter of the Jindivik air cushion system.

a. Weights

Figure 19 shows that as the cushion mass flow rate increases, the flutter amplitude also increases. In the weight test, 60-6, eight 2-pound weights were attached to the left side of the trunk every ten inches as depicted in Figure 20a. Results show that the flutter amplitudes of the trunk with weights were only slightly less than those flutter amplitudes exhibited by the clean trunk, A graph of flutter amplitudes versus accelerometer locations for the different cushion mass flow rates of test 60-6 is presented in Figure 21. Its results also show a sudden rise in amplitude as the cushion mass flow rate is increased.

In tests performed by H. S. Fowler (Reference 1), small weights were totally effective in stopping flutter. However, the 0.0035-inch-thick trunk used was a very thin lightweight transparent plastic membrane. Results of Ryken's tests (Reference 2) also indicated some success with weights but the weights that were used weighed 25 to 50 percent of the trunk's total weight.

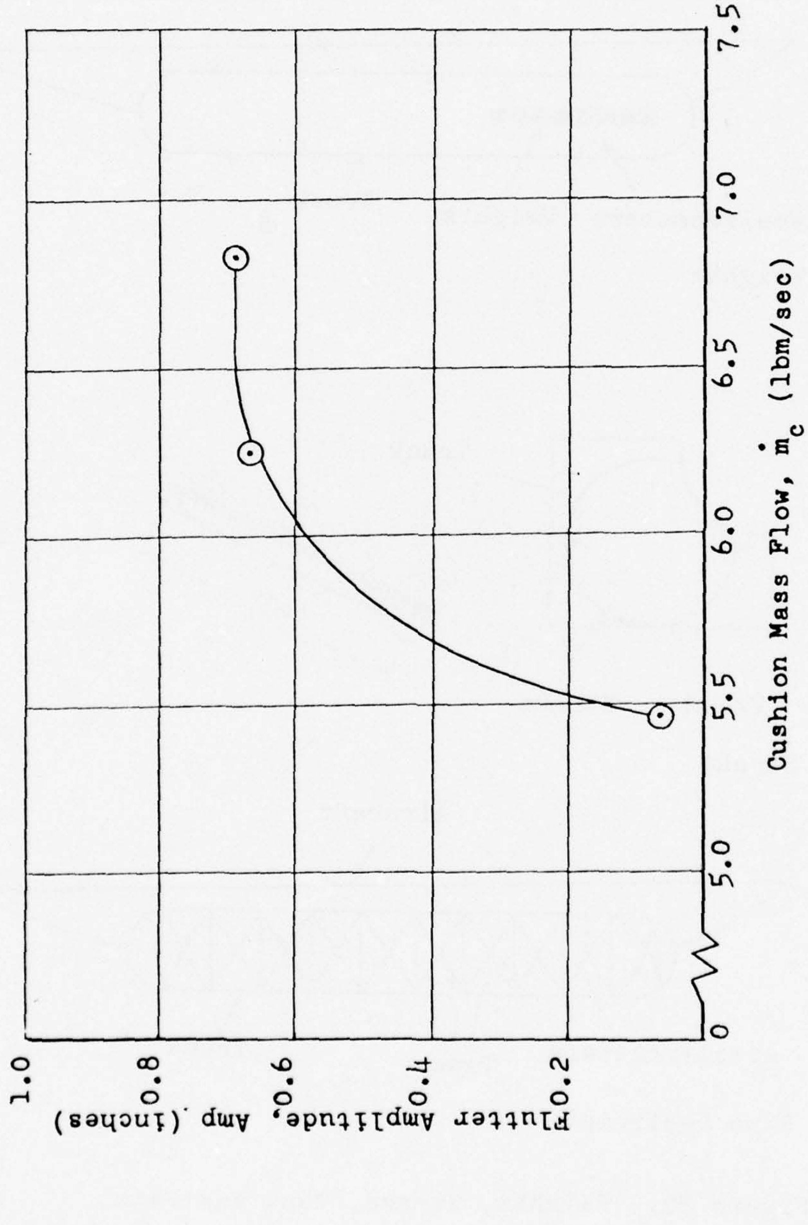
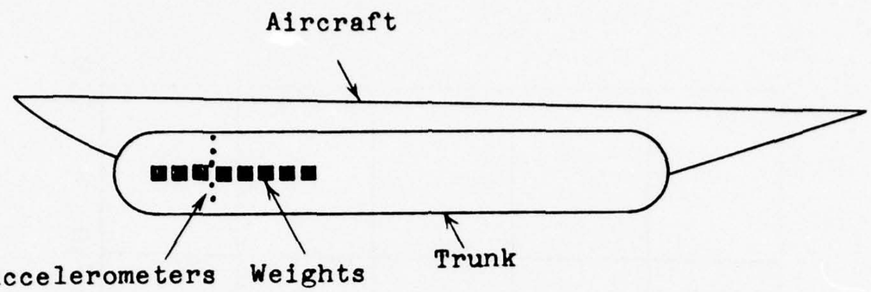
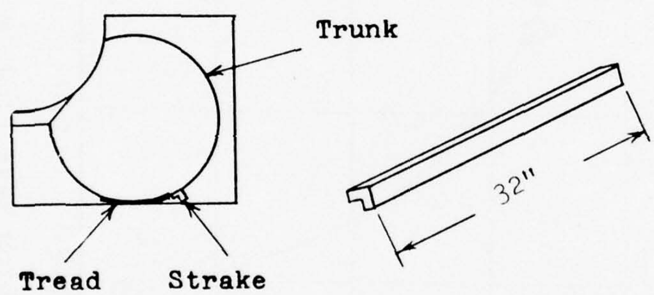


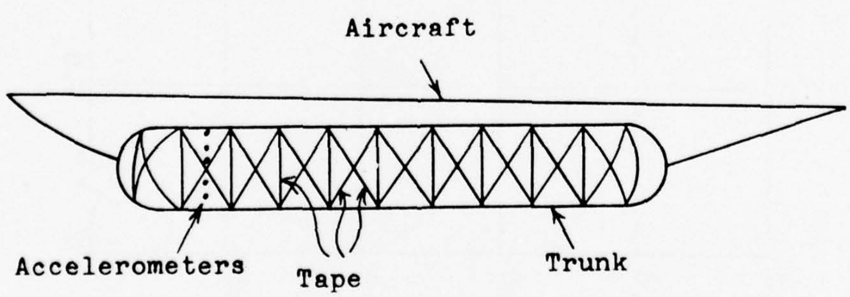
Figure 19. 3-D Weight Test 60-6, Flutter Amplitudes vs Cushion Mass Flows, Accl #10 only



a) Weights



b) Strake



c) Tape Restraint

Figure 20. Weights, Strake, Tape Restraint

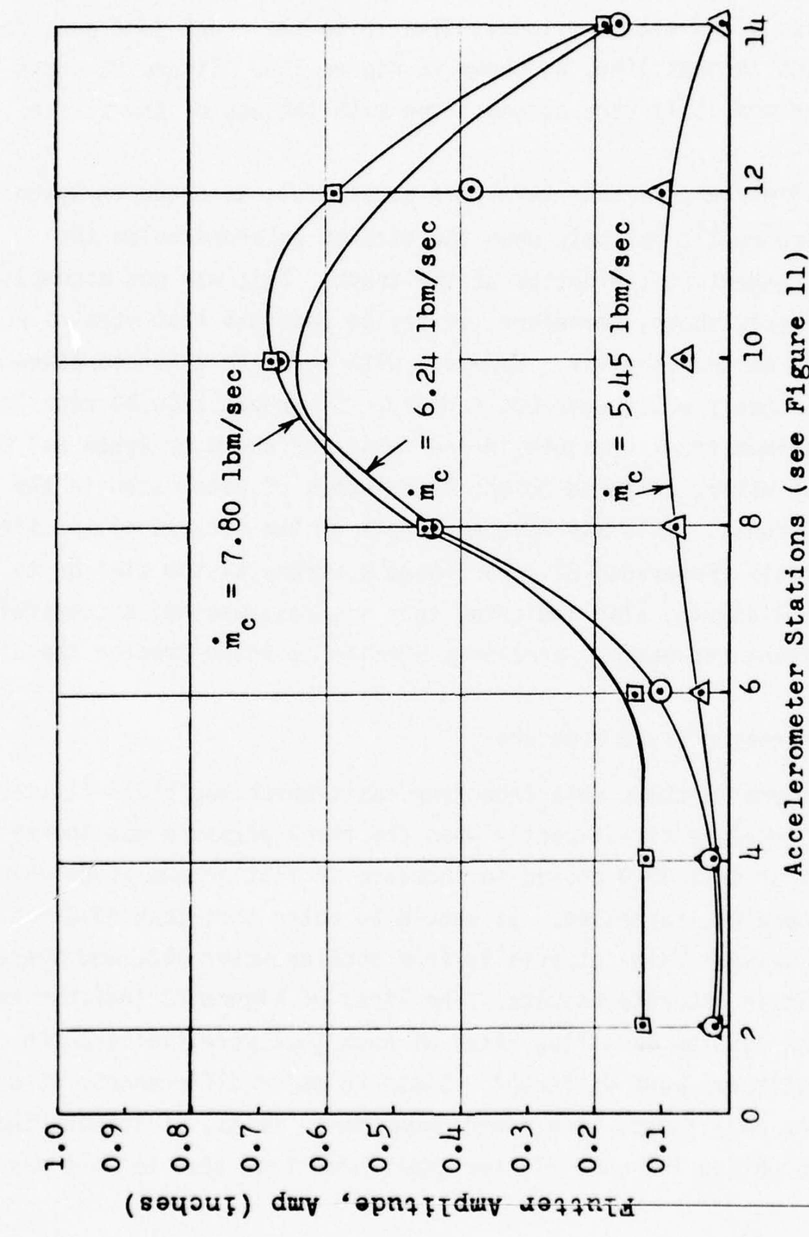


Figure 21. 3-D Weight Test 60-6, Lines of Varying Mass Flows

b. Strakes

Only two tests were performed with a strake on the 2-D trunk. The strake used was a one-inch-by-one-inch L-shaped piece of rubber, 32 inches long, and attached longitudinally to the trunk just outside of the ground tangent line, as shown in Figure 20b. Figure 22 shows that flutter was still very strong, even with the use of the strake.

Some strake experiments have been successful, as noted in Ryken's tests (Reference 2), but only when the strakes extended below the horizontal tangent at the bottom of the trunk. This was not accomplished in the two tests above; therefore, it may be possible that strakes would be effective on the Jindivik. However, with a strake extended below the trunk, it probably would wear out rapidly. It should also be recalled that the maximum trunk pressure in the tests performed by Ryken was only 10 inches of water, compared to the 49.8 inches of water used in the Jindivik's trunks. This may have an effect on the success of the strake. Gardner's tests (Reference 3), which used a strake system similar to that used on the Jindivik, also indicated that a strake was not successful. Gardner's trunk had maximum pressures similar to those used on the Jindivik.

c. Increased Trunk Pressure

Figure 23 shows data from four tests which had their flutter amplitudes increase significantly when the trunk pressure was increased. The results of test 63-9 showed no increase in flutter amplitude when trunk pressure was increased. It should be noted that test 63-9 had shown some unusual data, especially from accelerometer #12, and therefore, may not contain accurate results. The lines of Figure 23 indicate that although the cushion mass flow rates of each test were similar, the flutter amplitudes were different. Since no major differences, other than flutter amplitudes, were found among those tests, it appears that attempts to obtain the same flutter amplitudes from test to test may be difficult.

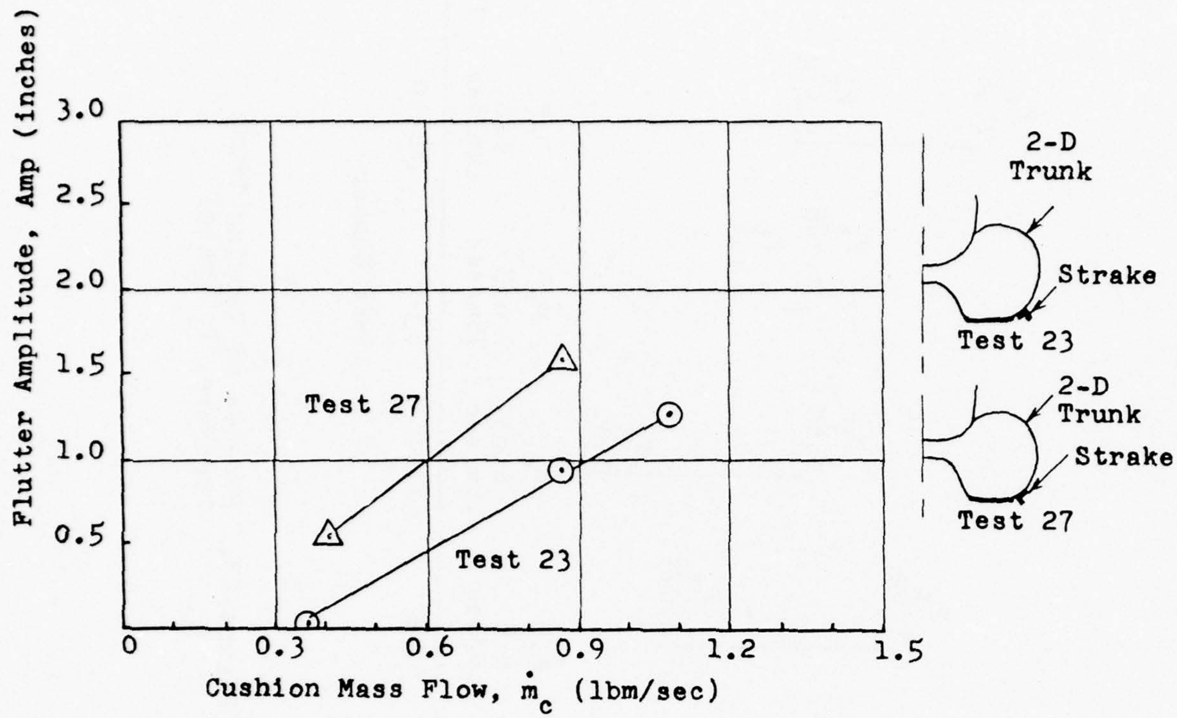


Figure 22. 2-D Strake Tests, Flutter Amplitudes vs Cushion Mass Flows

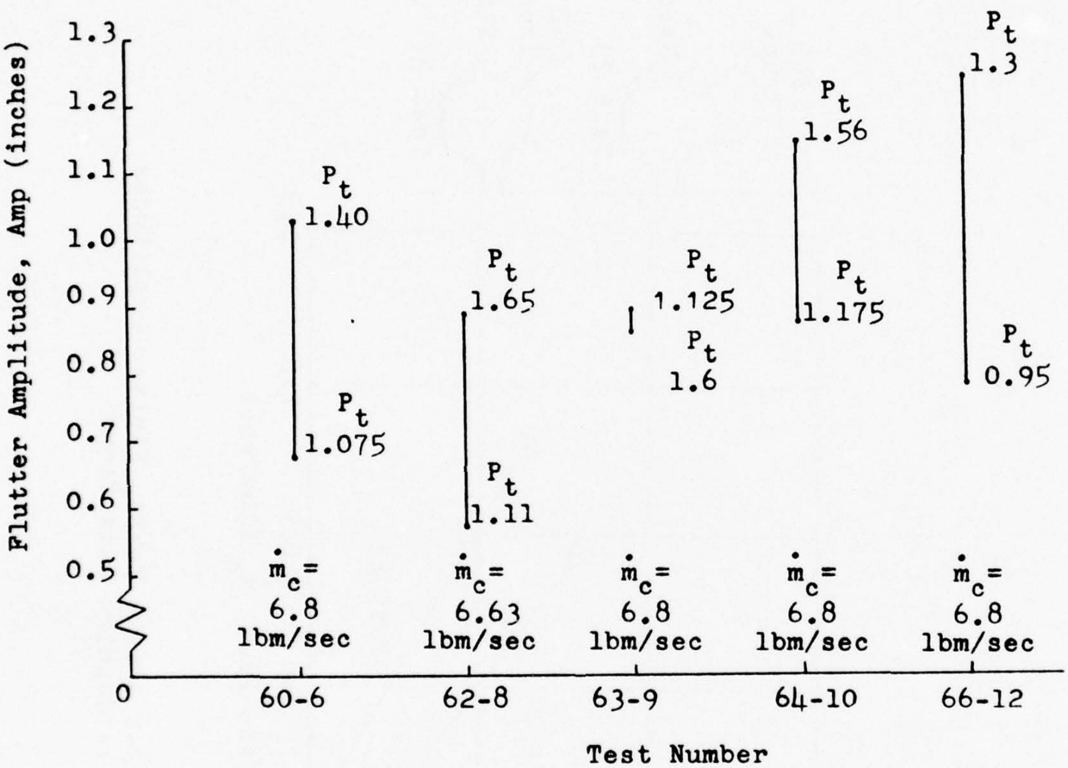


Figure 23. Effects of Varying Trunk Pressure, P_t (psig)

In the Bell Aerospace and Southwest Research reports, the flutter amplitude increased when the trunk pressure was decreased. This is the complete opposite of the test results contained herein. Again, a possible reason for this difference may be the lower trunk pressures used in those tests. The Bell tests had a maximum trunk pressure of 10 inches of water, while the maximum trunk pressures of the Southwest Research tests were around 24 inches of water. These values are less than half the maximum trunk pressures used on the Jindivik, which were around 49.8 inches of water.

The results of the above paragraphs indicate that there may be an optimum trunk pressure for each trunk design. It also appears that varying trunk pressure has no value in the total elimination of trunk flutter.

d. Tape Restraints

The tape restraint system was made of two-inch-wide strips of a nonelastic tape. Each piece was glued at the top and bottom of the trunk, and spaced eight inches apart. Between these vertical and parallel strips were crossed pieces of tape, as shown in Figure 20c. The idea was to restrain the trunk, which it did, and reduce the flutter amplitudes. Unfortunately, when the cushion mass flow was increased, the flutter again appeared, as indicated in Figures 24 and 25.

e. Stiffening Tube

The stiffening tube was located within the 2-D trunk section and attached to it, as shown in Figure 14. The stiffening tube, made of 15 oz/yd^2 neoprene coated nylon fabric, stiffened the trunk as it was pressurized to 10 psig. Like the tape restraint system, however, the stiffening tube did not reduce the trunk flutter. Figure 26 shows the flutter amplitudes obtained as a function of cushion mass flow rates.

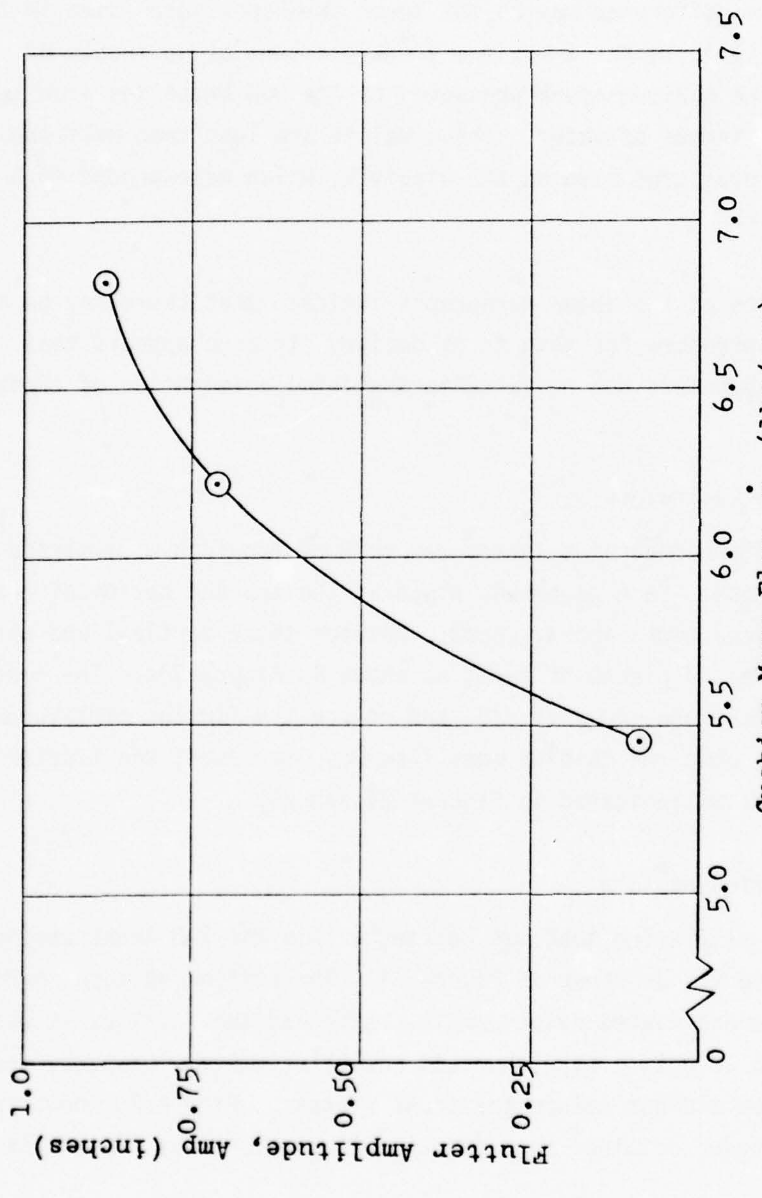


Figure 24. 3-D Tape Test 64-10, Flutter Amplitudes vs Cushion Mass Flows, Accl #10 only

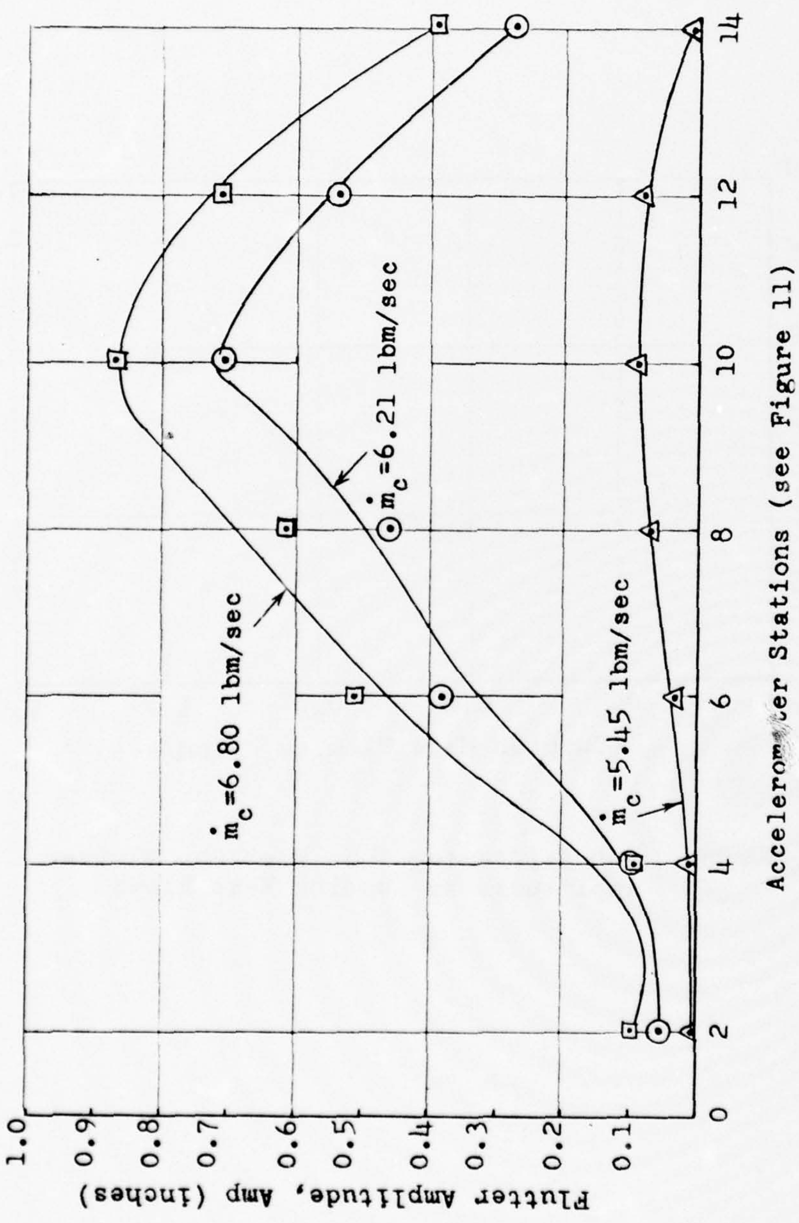


Figure 25. 3-D Tape Test 64-10, Lines of Varying Mass Flows

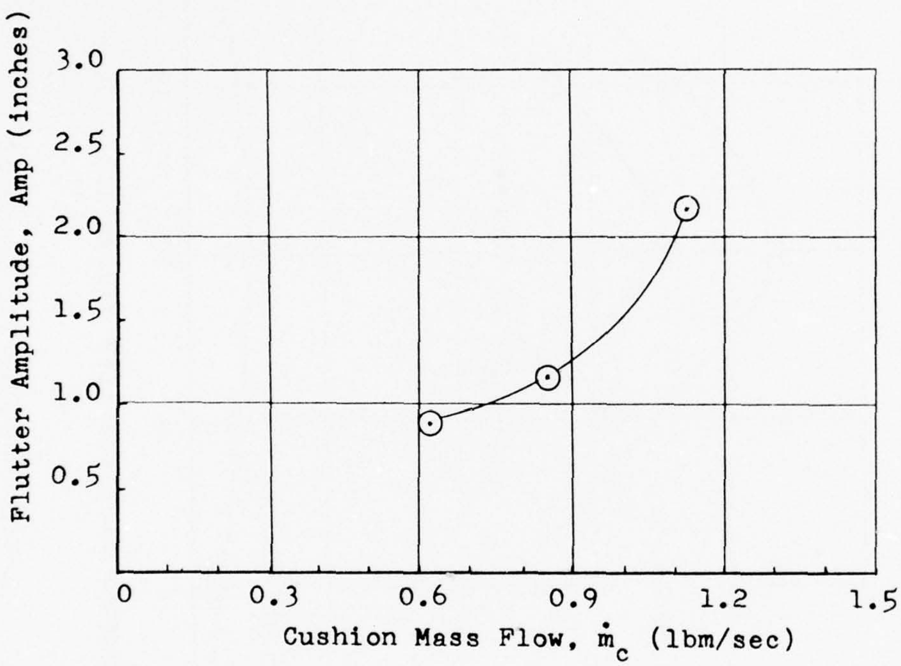


Figure 26. 2-D Stiffening Tube Test 24, Flutter Amplitudes vs Cushion Mass Flows

3. A REEVALUATION OF FLUTTER

The data derived from the previous tests were again reviewed, with special attention given to the floor static pressure readings. Figure 27 shows two typical floor pressure distributions taken during the same test. From this graph it is important to note that the pressure readings made just prior to flutter show a pressure difference of 0.93 psi between pressure taps 3 and 4 (see Figure 4). During flutter, the pressure difference between the same taps was only 0.60 psi. A higher pressure difference exists between the inside cushion cavity and the outside air before flutter than during flutter. These differences in pressures result from the fact that before flutter begins there is only a small gap between the ground and the trunk, which allows pressure to build up in the cushion cavity. As cushion flow is increased and flutter begins, the up and down movement of the trunk creates large gaps for the cushion air to escape. With these large gaps, the cushion air cannot build up to the same pressures it had prior to flutter.

The strip charts which recorded the floor pressure measurements also revealed some interesting data. As shown in Figure 28, section "a" represents a trace of the 10 floor pressure taps taken before flutter began, while Section "b" represents a trace of the same strip chart taken during flutter. The significant finding was noted when the peaks of the Section "b" trace were compared to the number of cycles recorded with the accelerometers. The cycles per second or frequency of the floor pressure readings recorded during flutter almost duplicate the frequency readings taken by the accelerometers.

The above observation and the results which showed that flutter amplitudes increased with increasing cushion flow rate helped in forming a theory about the nature of flutter. That theory is as follows: Before flutter begins, the cushion mass flow rate is small and the air inside the cushion cavity pushes outward and beneath the trunk uniformly and slowly. It gently holds up the trunk an infinitesimal amount and causes the trunk to move out a few inches. As the cushion mass flow rate continues to increase, the trunk cannot move outward any further. Instead,

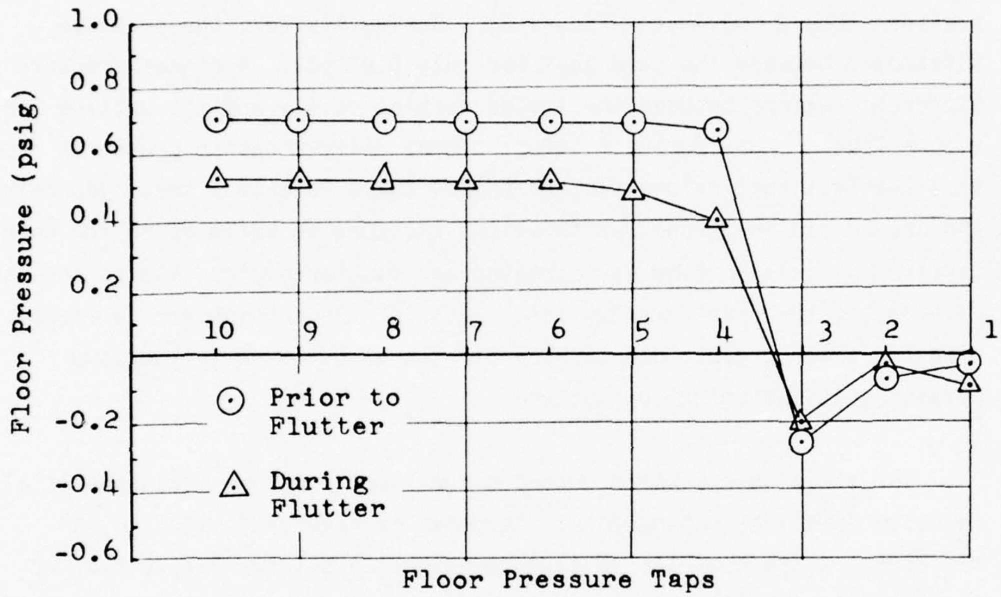
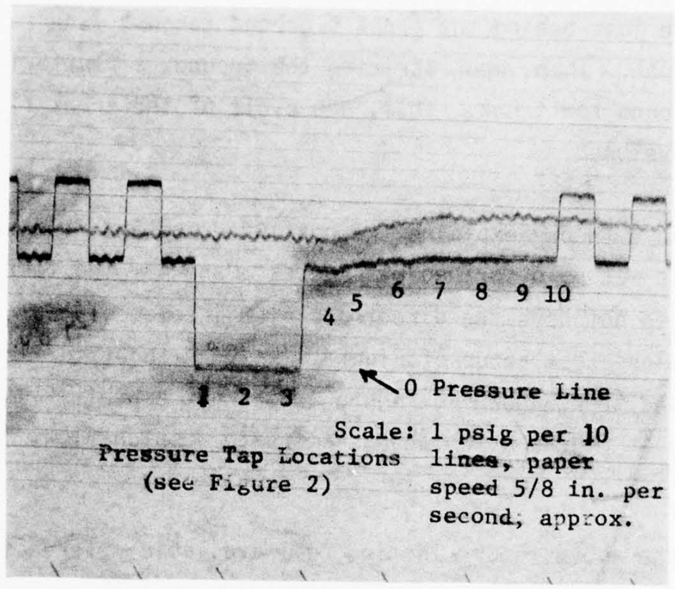
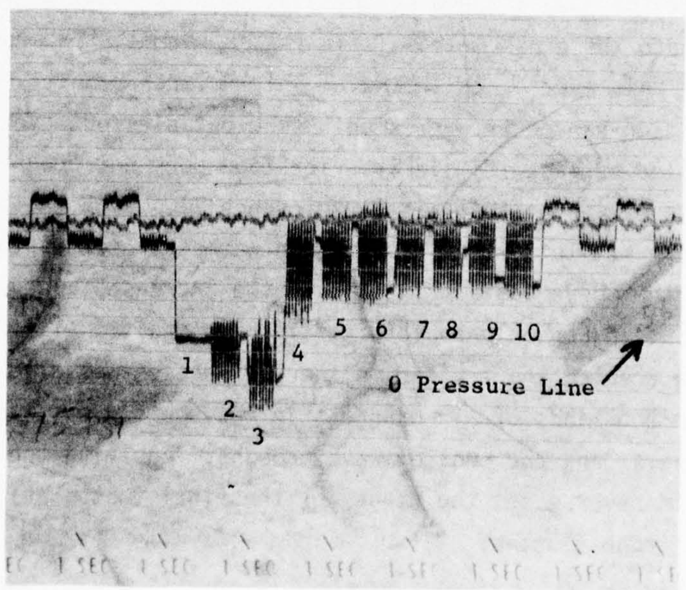


Figure 27. Floor Static Pressure Distributions, Test 10



(a) Prior to Flutter



(b) During Flutter

Figure 28. Floor Pressure Distribution Measurements

the trunk is lifted up and a gust of air escapes. With this occurrence, the pressure just behind the trunk's ground tangent line falls and so does the trunk. Then, upon striking the ground, a fluttering wave is sent out around the trunk. Thus, one cycle of the trunk flutter frequency has been developed.

The above theory explains the nonfluttering and fluttering trunk of the 2-D test setups described by Figures 3 and 4. The test setup of Figure 3 does not have the direct air flow into and out of the cushion cavity that the test setup of Figure 4 has. WIthout sufficient cushion mass flow the trunk shown in Figure 3 does not exhibit flutter, while the trunk shown in Figure 4, which has adequate cushion flow, does flutter easily.

With the above theory in mind, all available references were again surveyed and a number of interesting notes were found. In Reference 1, Fowler made the following statement: "When the Vehicle I was hovered off the asphalt and onto the short grass during the experiments, it was noticed that the buzz stopped abruptly as soon as about one-third of the skirt was onto the grass. This is in fact a normal phenomenon with vehicles of this type". In the Naval Ship Reserch report, Liu stated that "vibration can occur over smooth sand but dies out over a beach with a wave-rippled surface; similarly, vibration does not occur when encountered waves become of appreciable size" (Reference 7). With the previous theory on the nature of flutter, an explanation was developed as to why the flutter stopped in the above cases. Instead of the increased air flow forcing the trunk out and up only to let it fall, the additional air flow that should have created the flutter in the above cases was allowed to escape through the thousands of air channels in the short grass, the hundreds of sand canals, and the tens of wave troughs. Applying the above solutions in reverse set the stage for the final tests, which successfully eliminated trunk flutter.

4. TWO-DIMENSIONAL FLUTTER ELIMINATION TESTS

The final attempts to eliminate trunk flutter of the Jindivik ACRS system were divided into three categories. They were entitled: floor strips, tread strips, and tread pucks. The floor strips were made of strips of rubber tire tread which were 1 inch thick by 1 inch wide. They were of varying lengths and spaced 1/2 in. apart. The tread strips were 1/2 in. wide, 10 inches long, and either 1/8, 1/4, or 3/8 in. thick. A photograph of a tread strip configuration is shown in Figure 29. A tread puck is a tread strip that is 1 1/2 inches to 4 inches long. Throughout these tests the air flow into the trunk was held constant, while the cushion air flow was increased in definite increments.

a. Floor Strips

The group of floor strip tests were performed first to establish the fact that flutter would not occur if ground air channels were available for that additional quantity of cushion air flow, which was thought to produce flutter. These tests were successful and a total of six tests were run On the test matrix, Table 1, these were Tests 3 through 8. In these tests, the floor strips of each new test were shorter than the previous test, except for Test 4 which was a repeat of Test 3. Tests 3 and 4 had 18-inch long floor strips and no flutter was observed or recorded. Test 5 had 10-inch long floor strips located just below the 10-inch wide trunk tread. Again, no flutter was noted. Test 6 had 5-inch long floor strips located below the rear half of the trunk tread. No flutter was noted in Test 6. Test 7 had 2-inch long floor strips near the ground tangent line of the trunk tread. Flutter started at a mass flow rate of 1.3 lbm/sec with a peak-to-peak amplitude of 0.11 in. Test 8 consisted of 1-inch long floor strips and no flutter was noted. However, following Test 8, one of the floor corner blocks which were used throughout the 2-D tests to block an air flow gap created when the trunk section bowed at its sides during inflation, was found out of position. This could have created a large air flow channel negating the occurrence of flutter. With the knowledge that the floor treads would eliminate flutter, the next step was to put similar strips on the trunk tread itself.

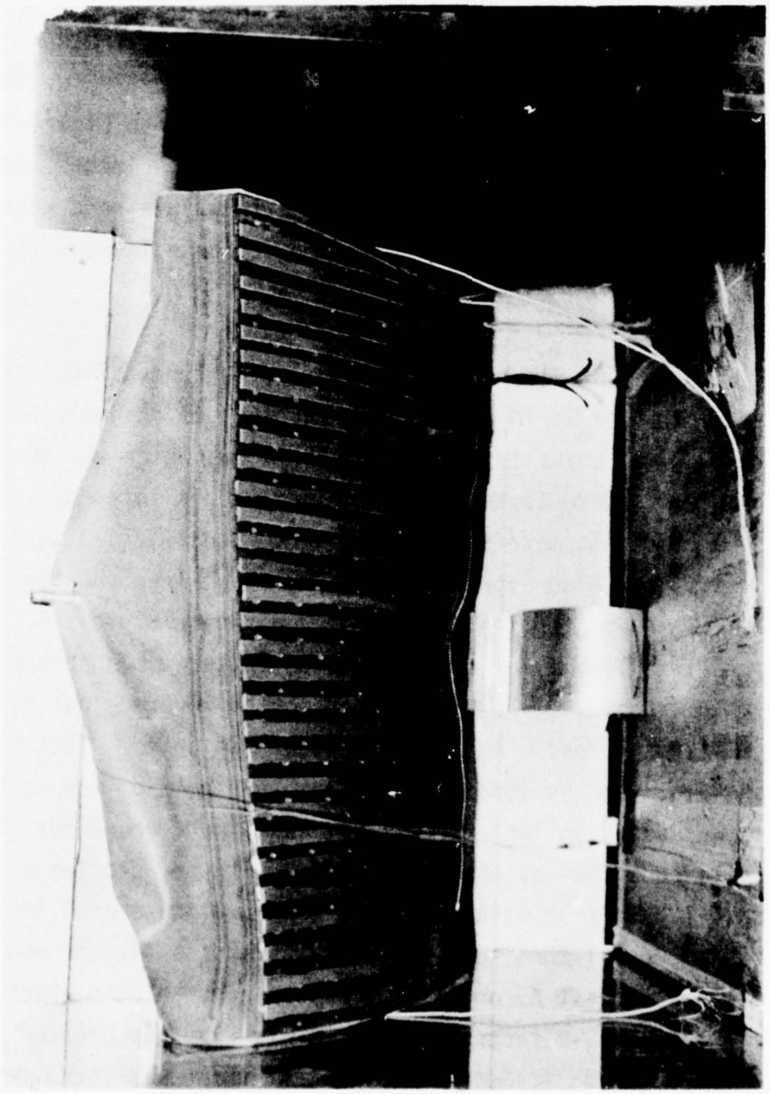


Figure 29. Tread Strips on the 2-D Test Trunk

b. Tread Strips

The decision to use tread strips was made because to develop a runway surface with grooves to stop trunk flutter would not be practical. But by attaching strips to the bottom of the trunk tread and thereby creating the necessary cushion air escape channels, the flutter eliminating device would always be with the aircraft no matter what the surface condition of the runway. To obtain the optimum tread strip configuration, varying strip thicknesses were tried. Each strip was 1/2 in. wide and either 1/8 in., 1/4 in., or 3/8 in. thick. All these tests were performed on the 2-D test setup and the tread strips were attached to the trunk tread with glue. A photograph showing a typical tread strip configuration is shown in Figure 29.

Test 11 was the first of the tread strip tests, and the strips were 1/2 in. wide, 1/8 in. thick, and 10 inches long. Tread strips were spaced 1/2 in. apart. The trunk began to flutter at a cushion air flow rate of 1.1 lbm/sec with an amplitude of 0.6 in.

Test 12 was similar to Test 11 except that the strips were spaced 1 1/2 inches apart. It was hoped that if the trunk would not deform downward and fill in the 1 1/2-inch-by-1/8-inch gap between each strip, enough open area might be available for the added cushion air flow to escape. However, this air channel must have deformed because flutter started again at a cushion air flow rate of 1.1 lbm/sec at an amplitude of 0.65 in. The results of Tests 11 and 12 showed that the 1/8-inch thick tread strips were too thin for the job.

In Test 13, the tread strips were 1/2 in. wide, 1/4 in. thick, 10 inches long, and spaced 1/2 in. apart. Flutter did not start until a cushion mass flow rate of 1.2 lbm/sec was reached. The amplitude at this point was 0.3 in. This was an improvement over Tests 11 and 12 since the flutter did not start until a higher cushion mass flow rate was reached and since a smaller amplitude was developed.

Test 14 was similar to 13 but the tread strip spacing was increased to 1 1/2 inches. The test was run up to a cushion mass flow rate of 1.4 lbm/sec and no flutter was observed or recorded. At this point, although flutter had been eliminated, further tests at other tread strip sizes were run to try to obtain the optimum configuration.

Tests 15, 16, 18, and 19 had tread strips that were 1/2 inch wide, 3/8 inch thick, 10 inches long, and spaced 1/2, 1 1/2, 3 1/2, and 7 1/2 inches, respectively. No flutter was noted in any of these tests. The maximum cushion mass flow rates for these tests ranged between 1.4 lbm/sec and 1.6 lbm/sec.

Test 30 was one more attempt with the 1/8-inch thick tread strips. The strips were 1/2 inch wide, 10 inches long, and spaced 3 inches apart. Strong flutter was recorded at a cushion mass flow rate of 1.04 lbm/sec, with an amplitude of 1.2 inches.

Test 31 was similar to Test 14 and was an attempt to reduce the amount of tread strips by increasing the spacing between them. In this test, the spacing between strips was increased from the 1 1/2 inches of Test 14 to 2 inches. The test was successful and no flutter was noted. To further optimize this method of eliminating flutter, the tread strips were shortened to a point where they were then referred to as tread pucks.

From all the results of the tread strip tests, those of Figure 30 are the most important. This figure shows a comparison of clean test results (Tests 1, 2, and 10) and the tread strip test results (Tests 14, 15, 18, and 19) on a graph of cushion pressure versus cushion mass flow rate. At the same cushion mass flow rate, those tread strip tests which completely eliminated trunk flutter had cushion pressures that were greater than those of the clean tests. This means that, although tread strips allow cushion air to escape, no loss in the required cushion pressure occurred and no increase in the driving air flow was required. Cushion pressure is important since it is the force that supports the aircraft.

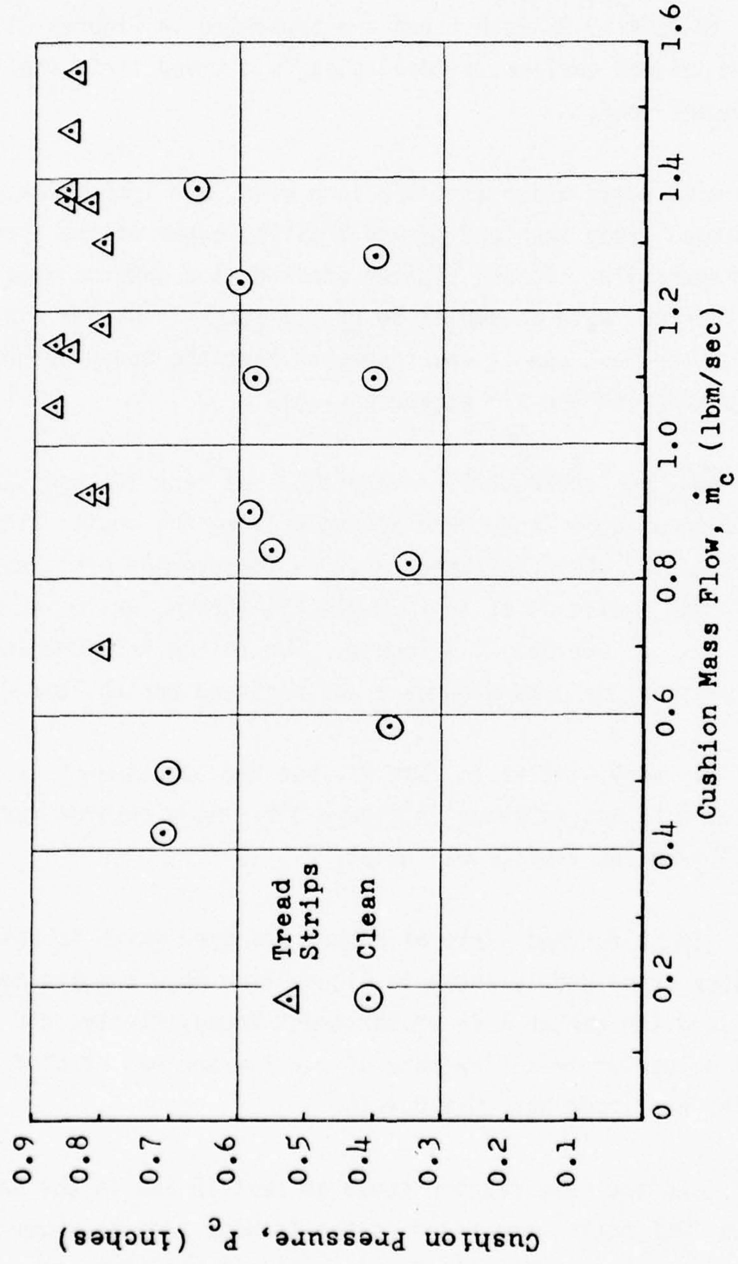


Figure 30. Cushion Pressures vs Cushion Mass Flows for Clean and Tread Strip Configurations

c. Tread Pucks

Eight tests were performed using tread pucks and their arrangements on the 10-inch-by-32-inch tread are presented in Figures 31, 32, and 33. As mentioned earlier, a tread puck is a tread strip that is only 1 1/2 to 4 inches long.

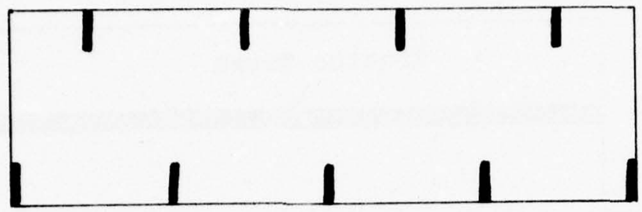
Test 20 used pucks which were 1/2 inch wide, 3/8 inch thick, 2 inches long and arranged along the leading and trailing edges of the trunk tread as shown in Figure 31a. Strong flutter started at a cushion mass flow rate of 0.9 lbm/sec, with an amplitude of 1.2 inches. No air gap was visible during the test and it was suspected that the trunk deformed downward, blocking off the air escape passages.

Test 21 was run under similar conditions as Test 20, and the same tread pucks were used but they were arranged along the center line as shown in Figure 31b. This appeared to be an improvement over Test 20 since the maximum amplitude of Test 20 was 2.1 inches, while the maximum amplitude of Test 21 was only 1.5 inches. Due to the instrumentation problem, no pressure or mass flow data was recorded during Test 21.

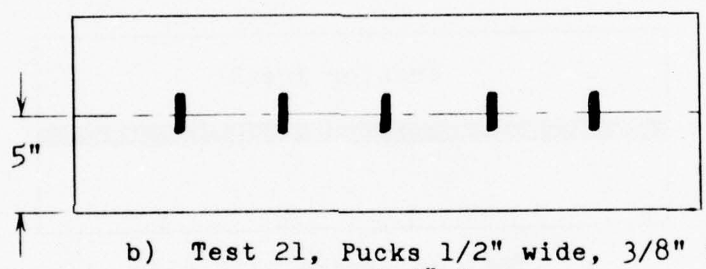
Test 22 was very similar to Test 21, but the pucks were increased to a length of 4 inches as shown in Figure 31c. At a cushion mass flow rate of 1.2 lbm/sec no flutter was noted.

For Test 25, a notched strip of rubber was used which is referred to as a tractor tread and is shown in Figure 32. When the tractor tread was placed along the center line of the trunk tread, flutter did not appear until a cushion mass flow rate of 1.2 lbm/sec was reached. At this point the amplitude was only 0.4 in.

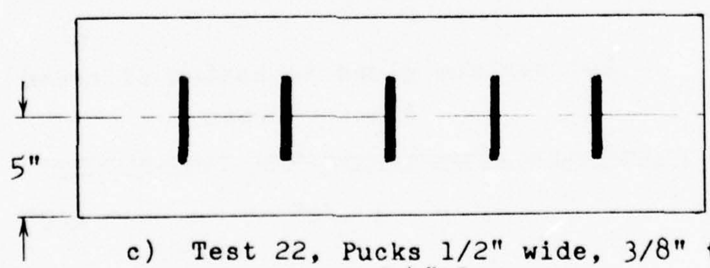
Test 26 used the same tractor tread as Test 25 and in the same location, but four pucks were added to the leading edge as shown in Figure 32b. Although no vibration data was available since the machine was not turned on, the flutter that did appear was less than that of Test 25.



a) Test 20, Pucks 1/2" wide, 3/8" thick and 2" long

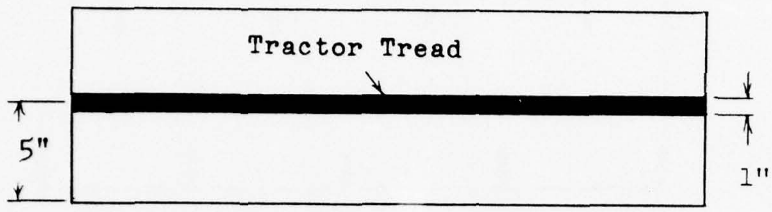


b) Test 21, Pucks 1/2" wide, 3/8" thick and 2" long

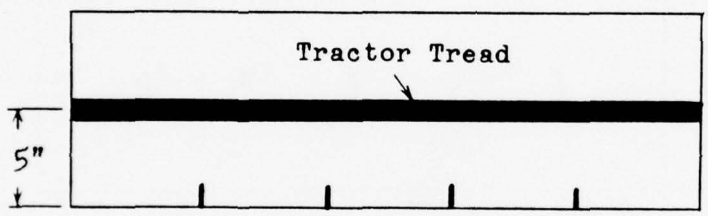


c) Test 22, Pucks 1/2" wide, 3/8" thick and 4" long

Figure 31. Tread Pucks on 2-D Trunk Tread, Tests 20, 21, and 22



a) Test 25



b) Test 26, Pucks 1/2" wide, 1/4" thick, and 1" long

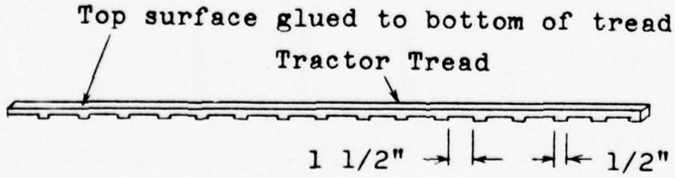
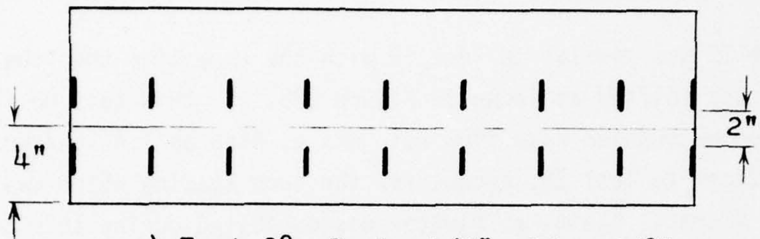
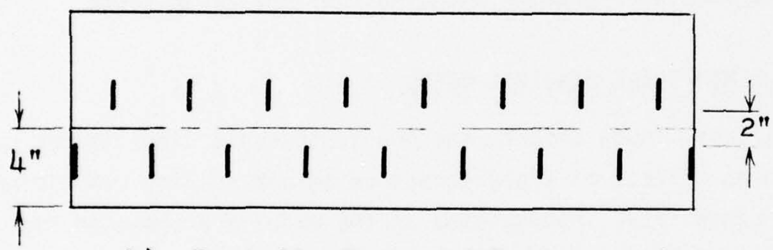


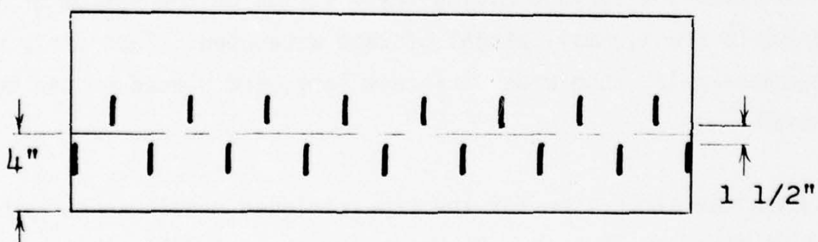
Figure 32. Tractor Tread Tests 25 and 26



a) Test 28, Pucks 1/2" wide, 3/8" thick, and 1 1/2" long



b) Test 29, Pucks 1/2" wide, 3/8" thick, and 1 1/2" long



c) Test 32, Pucks 1/2" wide, 3/8" thick, and 1 1/2" long

Figure 33. Tread Pucks on 2-D Trunk Tread, Tests 28, 29, and 32

Two rows of pucks were used for Test 28 as shown in Figure 33a, and strong flutter was noted at a cushion mass flow rate of 1.4 lbm/sec. The amplitude at that point was 2.2 inches.

Test 29 was similar to Test 28 with the exception that the back row of pucks was shifted as shown in Figure 33b. In this test no flutter was noted and the cushion mass flow rate was as high as 1.4 lbm/sec. Test 32 was identical to Test 29, except for the puck spacing which was decreased to 1 1/2 inches. Again, no flutter was exhibited during this test.

Like the results of the tread strip tests, those tread pucks which eliminated trunk flutter had, at a given cushion mass flow rate, cushion pressures that were greater than those of the clean tests.

5. ONE-TENTH-SCALE JINDIVIK TESTS

As a last minute effort, the one-tenth-scale Jindivik was used to observe the effects of tread strips on an air cushion vehicle which had dynamic capability. Photographs of the model are shown in Figure 34. The full-scale Jindivik was not available for these tests; however, it is hoped that such tests will be performed on it in the future.

To develop a surface having tread strips on the bottom of the one-tenth-scale trunk, small pieces of tape were used. Each strip was approximately 1/8 inch wide, 3 inches long, and placed on the bottom of the trunk.

When the air system for the tape-stripped model was turned on, it appeared that the flutter, which was present on earlier tests of the clean model, was reduced. Unfortunately, the trunk on this model was worn and had a few small holes. Therefore, no further results of these tests are presented as they might not be completely valid.

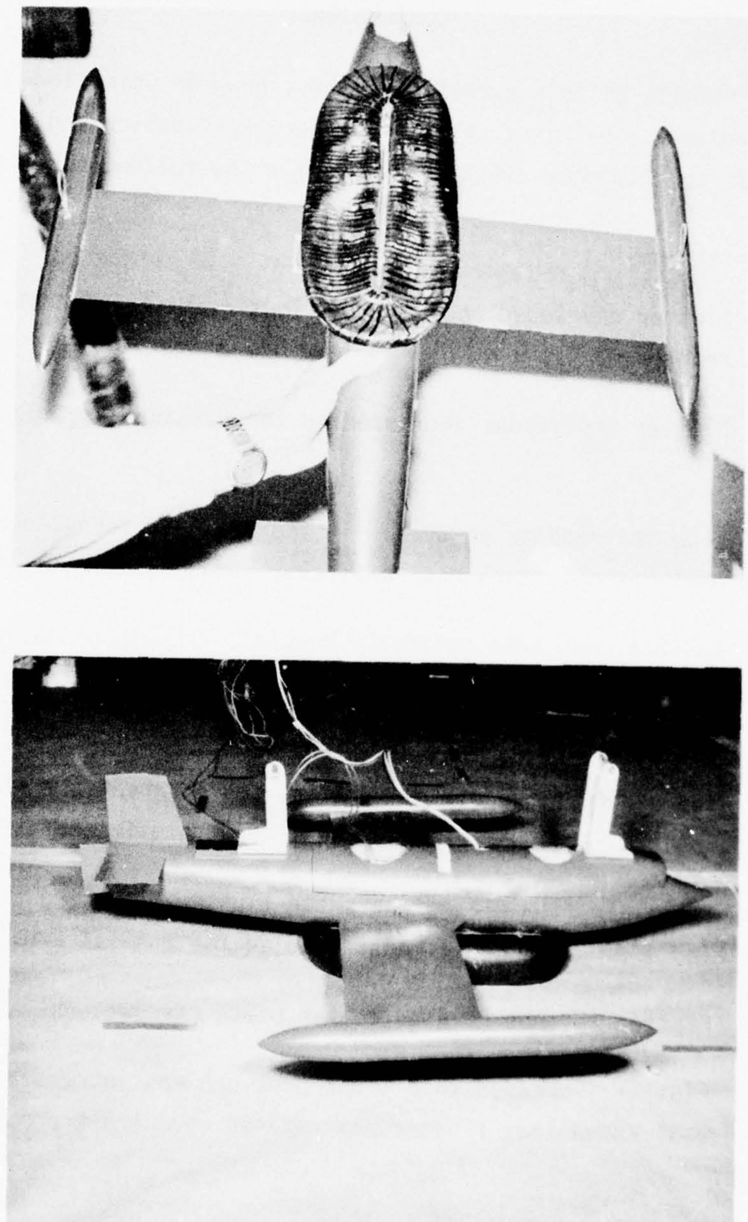


Figure 34. One-Tenth-Scale Jindivik

SECTION V

CONCLUSIONS

The results of this experimental test program using two-dimensional and three-dimensional test setups for the investigation and development of methods to eliminate trunk flutter allow the following conclusions:

1. VERIFICATION:

(a) Flutter developed when a sufficient quantity of cushion mass flow was reached.

(b) Flutter amplitudes increased as the cushion mass flow was increased.

(c) Like the results discussed in the Boeing report (Reference 3), air flow deflecting strakes had no flutter reducing effects.

(d) Weights were only partially helpful. The 16 pounds added to the Jindivik trunk only reduced flutter amplitude by approximately 12 percent.

(e) The use of floor strips verified the observations that ground surfaces, such as grass or rippled sand, tend to eliminate trunk flutter.

(f) Trunk air flow did not have the flutter producing effects that cushion flow did. This was demonstrated in the initial 2-D tests.

(g) Flutter was not related to fan blade revolutions.

(h) Flutter increased when trunk pressure was increased. Gardner (Reference 3) found that flutter was reduced when trunk pressure was reduced.

2. CONTRADICTIONS

(a) Although strakes were not found successful in this report, Ryken (Reference 2) showed that strakes were effective in reducing flutter when the strakes extended below the horizontal tangent to the bottom of the trunk. This characteristic was not a part of the strake setup used in this report or the Boeing report.

(b) In this report, increasing trunk pressure caused the flutter amplitude to increase, while in the Ryken and Bass reports (References 2 and 4) it was determined that lowering trunk pressure had the same effect. It should be recalled that Ryken and Bass had trunk pressures less than half the trunk pressures used in the Jindivik tests. This may very well be an explanation for the contradiction.

3. FINDINGS

(a) Flutter amplitudes and frequencies can be eliminated with tread strips, tread pucks, or some similar design which would create air passageways along the bottom of the trunk tread. These channels allow the flutter-producing cushion air flow to escape. Results of the tread strip tests indicate that the 1/4-inch thick, 1/2-inch wide, 10-inch long, and 2-inch spaced tread strip configuration was very satisfactory in eliminating trunk flutter. From the tread puck tests, the configuration which had two rows of pucks on either side of the ground tangent line, as shown in Figure 33, also had good flutter eliminating characteristics. These methods of eliminating trunk flutter have, at a given cushion mass flow rate, cushion pressures that are greater than those of the clean test. This means that no loss in the required cushion pressure occurred and that no increase in the driving air flow was required.

(b) The stiffening tube and the tape restraint attempts to reduce flutter were not successful.

(c) The flutter frequencies around the trunk's circumference were similar, but the flutter amplitudes differed. Basically, the outside trunk surfaces had higher flutter amplitudes than the inner trunk surface. In most tests, accelerometer number 10 exhibited the highest flutter amplitude (see Figure 11).

(d) The two-dimensional full-scale trunk configuration was a simple and reliable method to investigate flutter. Also, the results obtained through its use appeared to be applicable to the three-dimensional full-scale trunk.

(e) Depending upon the trunk configuration, the Jindivik's trunk exhibited strong flutter ranging between 20 and 30 hertz. The 2-D tests had a maximum flutter amplitude of 2.77 inches, while the 3-D test had a maximum flutter amplitude of 1.97 inches.

SECTION VI

RECOMMENDATIONS

Based on the results of these tests, it is recommended that the following items be considered:

(a) When designing an air cushion system, keep cushion mass flow to a minimum and trunk flow to maximum, if the elimination of trunk flutter is of importance.

(b) When high cushion flow is required, design the bottom of the trunk tread with grooves or channels that will allow the flutter-producing cushion air to escape uneventfully.

(c) Test a full-scale or sufficiently large air cushion system that has dynamic capabilities and a trunk tread with permanently affixed tread strips to verify the results of the static tests performed in this report. Such a program might also include tests to establish the optimum size and location of the tread strips.

APPENDIX

FLUTTER TEST DATA

Figures 35 through 39 shown in the back of this appendix, presents the modes of the trunk flutter as exhibited in test sections 10A through 10E, respectively (see Table 2). These plots are representative of the vibration data recorded on all tests which used the lightweight accelerometers. On these plots any high acceleration forces noted prior to 10 cps are due to the nature of the analyzer and should be disregarded. Vibration data of this sort will be made available on all those tests which were monitored with the vibration recording equipment. A report will be written by personnel of the vibration analysis branch, AFFDL/FYT.

Most of the tests were performed in segments of increased cushion mass flow rates. At each new cushion mass flow rate, all test parameters were held constant so that an accurate vibration analysis of that section could be taken. Each of these segments were lettered for identification, and charts such as Figures 35 through 39 were obtained. These figures show plots of acceleration forces versus flutter frequencies. In the three-dimensional tests, the flutter amplitudes along with the acceleration forces and frequencies were computed and printed out with aid of a computer program. However, in the two-dimensional tests, the flutter amplitudes were calculated with the use of the following equation:

$$\text{Amp} = \frac{G}{(0.0511)(0.707)f^2}$$

where:

G = acceleration (ft/sec^2)

f = flutter frequency (cps)

Amp = flutter amplitude (in.)

The measured and calculated test parameters for the two-dimensional tests are listed in Table 2. As mentioned above, each test is divided into sections of relatively constant cushion mass flow and are designated by capital letters following the test number. The dash lines in Table 2

indicate that there was no flutter and therefore, no frequencies, acceleration forces, or flutter amplitudes. In those test sections which have TP (transitional phase) printed in the cushion mass flow rate column, the cushion mass flow rate and the corresponding pressure readings are not shown because the cushion mass flow rate was changing during those sections.

Table 3 lists the floor pressures recorded by the Scanivalve for a number of the 2-D tests. Data from those tests that had tread strips or pucks attached may exhibit some questionable readings, since it is possible that they could have covered some of the floor pressure taps during the tests. Some tests do not have floor pressure readings at all. This is due to the fact that to obtain values that had some meaning, all 10 floor pressure readings had to be obtained from areas of constant cushion mass flow rates. In some cases, the 5 second interval required to record all 10 floor pressure ports was not completely in the bounds of such a region.

Table 4 lists those test parameters recorded during periods of constant cushion mass flow for the three-dimensional tests.

Table 5 lists those frequencies and acceleration forces recorded and the calculated flutter amplitudes, which were obtained from each of the seven accelerometers placed around the trunk for the three-dimensional tests. This table is also divided into test sections that correspond to the test sections of Table 4.

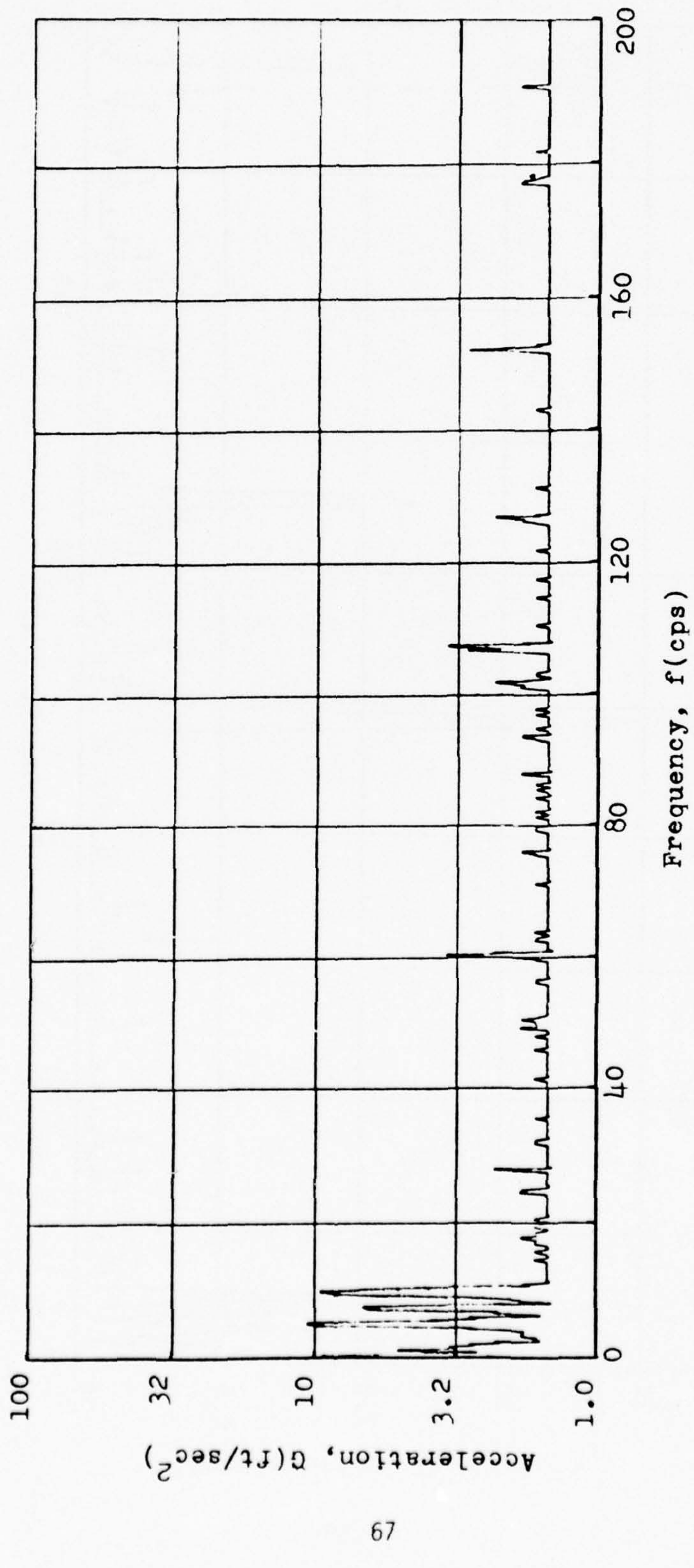


Figure 35. Trunk Flutter at $\dot{m}_c$ = 0.03 lbm/sec, Test 10A

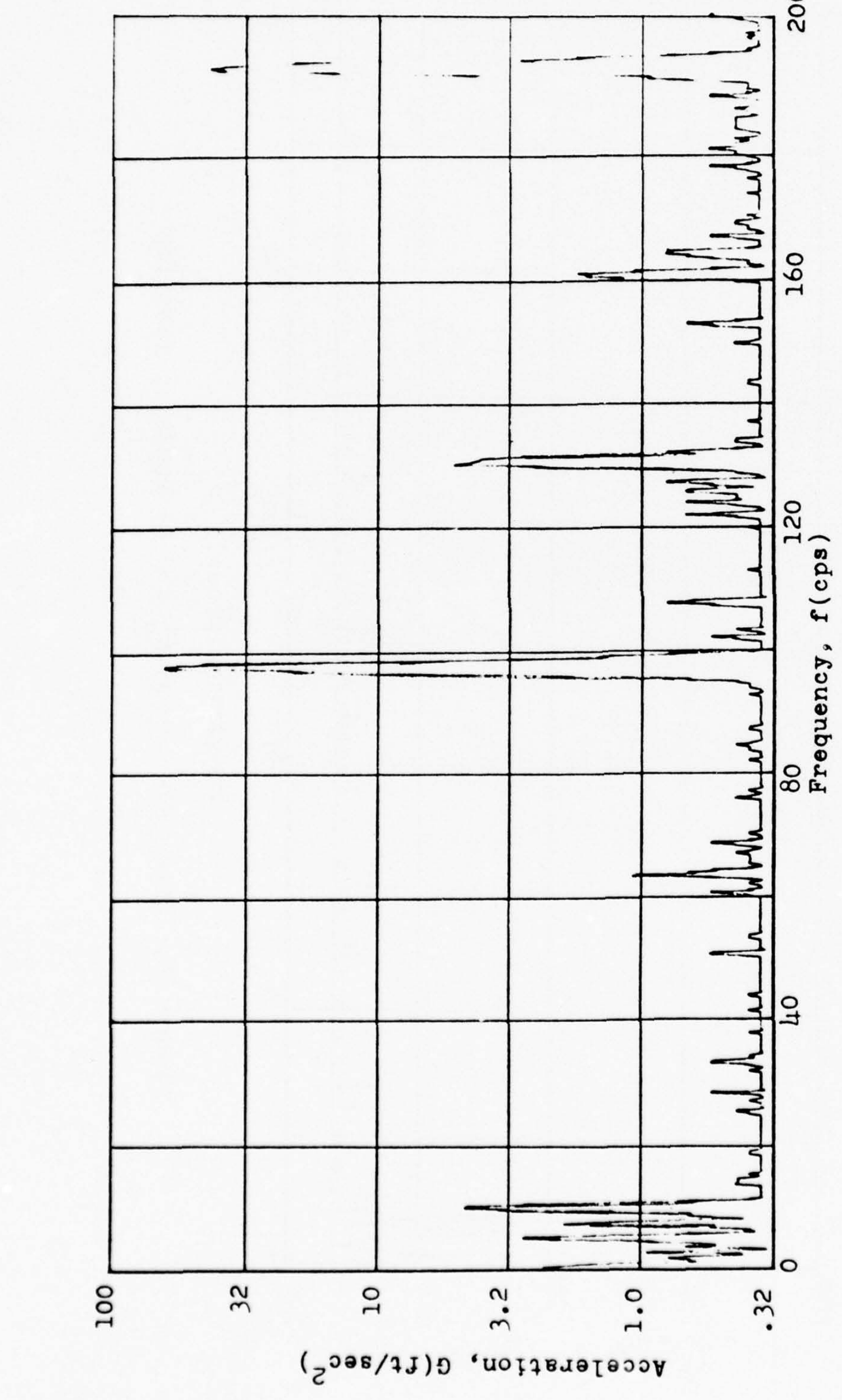


Figure 36. Trunk Flutter at $\dot{m}_c$ = 0.43 lbm/sec, Test 10B

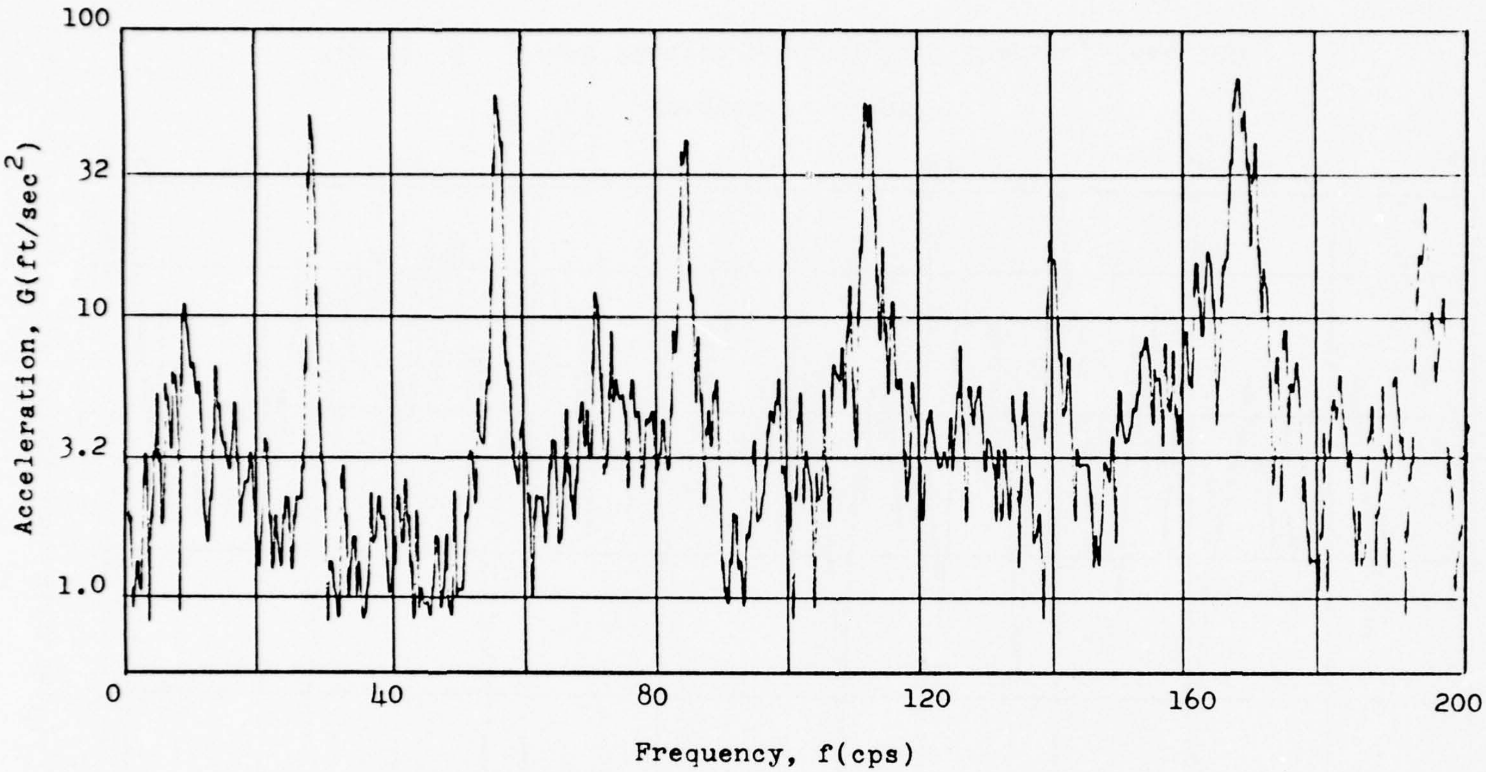


Figure 37. Trunk Flutter at $\dot{m}_c$ = 0.90 lbm/sec, Test 10C

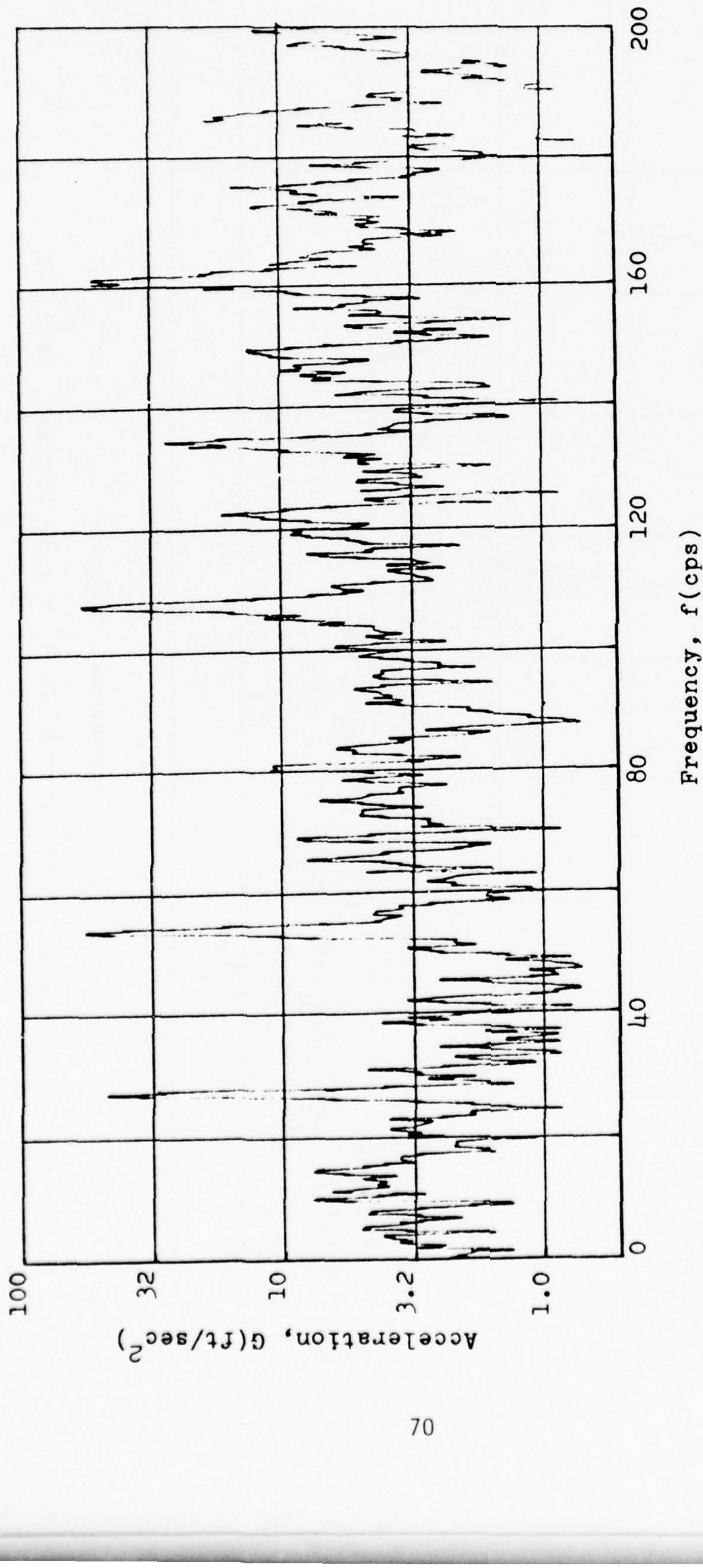


Figure 38. Trunk Flutter at $\dot{m}_c$ = 1.10 lbm/sec, Test 10D

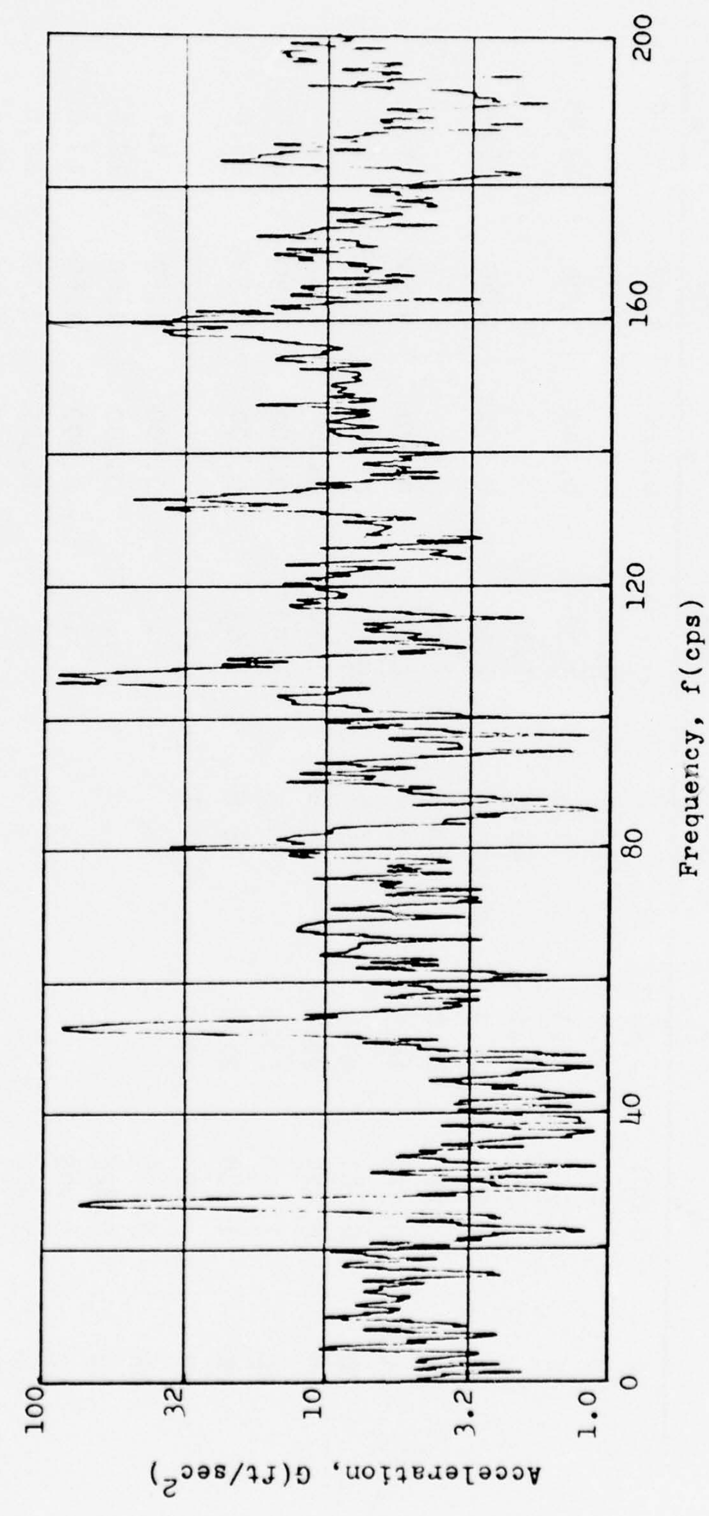


Figure 39. Trunk Flutter at $\dot{m}_c$ = 1.20 lbm/sec, Test 10E

TABLE 2. TWO-DIMENSIONAL FLUTTER DATA

Test # & Section	Cushion Flow Rate (lbm/sec) $\dot{m}_c$	Flutter Frequency (cps) f	Acceleration (rms) G	Flutter Amplitude (inches) Amp	Cushion Pressure (psig) P_c	Trunk Pressure (psig) P_t	Ejector Pressure (psig) P_e
1A	0.001	-	-	-	0.625	1.37	5.50
1B	TP	97.0	125.0	0.26			
1C	0.513	27.3	71.6	1.88	0.700	1.06	13.50
1D	TP	27.6	43.2	1.11			
1E	0.844	27.3	100.0	2.62	0.500	0.80	16.00
1F	TP	28.0	56.9	1.42			
2A	0.375	75.0	32.0	0.11	0.370	0.600	7.0
2B	0.581	24.0	19.3	0.66	0.375	0.565	9.5
2C	0.825	20.0	32.6	1.59	0.350	0.475	13.3
2D	1.100	20.8	33.9	1.53	0.400	0.500	20.0
2E	1.288	21.0	36.8	1.63	0.400	0.525	25.0
2F	TP	20.8	37.1	1.68			
4A	0.578	-	-	-	0.200	1.57	7.7
4B	0.828	-	-	-	0.300	1.60	12.6
4C	0.998	-	-	-	0.390	1.60	17.0
4D	1.220	-	-	-	0.325	1.17	22.0
4E	1.340	-	-	-	0.325	1.10	26.0
4F	1.480	-	-	-	0.325	1.07	30.5

TABLE 2. TWO-DIMENSIONAL FLUTTER DATA (continued)

Test # & Section	Cushion Flow Rate (lbm/sec) $\dot{m}_c$	Flutter Frequency (cps) f	Acceleration (rms) G	Flutter Amplitude (inches) Amp	Cushion Pressure (psig) P_c	Trunk Pressure (psig) P_t	Ejector Pressure (psig) P_e
5C	0.997	-	-	-	0.40	1.85	17.0
5D	1.230	-	-	-	0.40	1.60	23.5
5E	1.360	-	-	-	0.34	1.17	26.3
5F	1.500	-	-	-	0.34	1.10	31.0
6C	0.719	-	-	-	0.77	1.120	16.3
6D	0.925	-	-	-	0.80	0.950	21.3
6E	1.106	-	-	-	0.81	0.925	24.8
6F	1.368	-	-	-	0.80	0.920	31.5
7C	0.856	-	-	-	0.79	1.17	16.8
7D	TP	65.8	12.2	0.06			
7E	1.306	65	23.4	0.11	0.89	1.00	30.8
8C	0.756	-	-	-	0.78	1.300	17.5
8D	TP	-	-	-			
8E	TP	-	-	-			
8F	1.325	-	-	-	0.84	0.975	31.0
10A	0.031	-	-	-	0.640	1.07	8.0
10B	0.425	95.0	71.7	0.16	0.710	1.06	13.0
10C	0.900	27.0	62.4	1.67	0.580	0.85	17.6

TABLE 2. TWO-DIMENSIONAL FLUTTER DATA (continued)

Test # & Section	Cushion Flow Rate (lbm/sec) $\dot{m}_c$	Flutter Frequency (cps) f	Acceleration (rms) G	Flutter Amplitude (inches) Amp	Cushion Pressure (psig) P_c	Trunk Pressure (psig) P_t	Ejector Pressure (psig) P_e
10D	1.093	26.8	50.5	1.37	0.575	0.80	22.0
10E	1.240	25.6	77.4	2.31	0.600	0.80	26.0
10F	1.380	25.8	94.4	2.77	0.660	0.79	30.5
11B	0.513	-	-	-	0.800	1.22	14.5
11C	0.738	-	-	-	0.825	1.17	17.5
11D	1.063	26	20.4	0.59	0.700	0.925	23.0
11E	TP	25.2	21.1	0.65			
11F	1.244	25.0	16.4	0.51	0.660	0.900	26.5
12C	0.762	-	-	-	0.75	1.070	17.0
12D	1.063	26.4	23.1	0.65	0.62	0.875	22.0
12E	1.230	25.6	9.7	0.29	0.61	0.850	26.0
13B	0.219	-	-	-	0.82	1.50	12.6
13C	0.713	-	-	-	0.86	1.30	18.0
13D	0.900	-	-	-	0.87	1.15	22.0
13E	1.206	25.0	10.5	0.33	0.74	1.00	26.5
13F	1.375	24.0	7.3	0.25	0.75	0.95	31.0
14D	0.931	-	-	-	0.8	1.08	21.5
14E	1.181	-	-	-	0.8	1.03	26.3

TABLE 2. TWO-DIMENSIONAL FLUTTER DATA (continued)

Test # & Section	Cushion Flow Rate (lbm/sec) $\dot{m}_c$	Flutter Frequency (cps) f	Acceleration (rms) G	Flutter Amplitude (inches) Amp	Cushion Pressure (psig) P_c	Trunk Pressure (psig) P_t	Ejector Pressure (psig) P_e
14F	1.313	-	-	-	0.8	1.00	30.0
15B	0.300	-	-	-	0.67	1.47	11.0
15C	0.700	-	-	-	0.80	1.37	16.5
15D	1.063	-	-	-	0.87	1.22	24.0
15E	1.156	-	-	-	0.87	1.15	27.0
15F	1.360	-	-	-	0.89	1.10	32.5
16D	0.939	-	-	-	0.66	1.16	19.5
16E	1.156	-	-	-	0.75	1.09	25.7
16F	1.363	-	-	-	0.82	1.08	31.7
17B	0.500	-	-	-	0.66	1.550	13.0
17C	0.794	-	-	-	0.74	1.250	17.2
17D	0.994	-	-	-	0.81	1.170	23.0
17E	1.218	27.6	6.5	0.17	0.75	1.050	27.0
17F	1.431	27.0	7.6	0.20	0.72	0.975	32.5
18D	0.928	-	-	-	0.82	1.15	22.0
18E	1.138	-	-	-	0.85	1.10	26.3
18F	1.375	-	-	-	0.85	1.05	32.5

TABLE 2. TWO-DIMENSIONAL FLUTTER DATA (continued)

Test # & Section	Cushion Flow Rate (lbm/sec) $\dot{m}_c$	Flutter Frequency (cps) f	Acceleration (rms) G	Flutter Amplitude (inches) Amp	Cushion Pressure (psig) P_c	Trunk Pressure (psig) P_t	Ejector Pressure (psig) P_e
19D	1.375	-	-	-	0.85	1.040	32.5
19E	1.469	-	-	-	0.85	1.000	35.5
19F	1.550	-	-	-	0.84	0.975	38.0
20B	0.375	68.8	3.5	0.014	0.70	1.125	12.2
20C	0.880	30.0	55.7	1.21	0.59	0.970	17.5
20D	1.044	27.7	82.2	2.09	0.57	0.870	21.0
21B		97.7	39.4	0.08			
21C		96.8	63.7	0.13			
21D		28.5	63.7	1.53			
22C	0.713	-	-	-	0.60	0.93	14.5
22G	1.162	-	-	-	0.79	0.90	26.0
23B	0.375	81.6	10.0	0.03	0.72	1.10	12.5
23C	0.863	28.0	37.7	0.94	0.60	0.90	17.4
23D	TP	27.7	30.2	0.77			
23E	1.075	26.0	44.1	1.28	0.58	0.85	22.0
24B	0.625	29.0	38.4	0.89	0.575	0.90	13.0
24C	0.856	27.6	45.1	1.16	0.540	0.84	16.0
24D	1.125	25.8	73.3	2.15	0.520	0.79	22.3

TABLE 2. TWO-DIMENSIONAL FLUTTER DATA (concluded)

Test # & Section	Cushion Flow Rate (lbm/sec) $\dot{m}_c$	Flutter Frequency (cps) f	Acceleration (rms) G	Flutter Amplitude (inches) Amp	Cushion Pressure (psig) P_c	Trunk Pressure (psig) P_t	Ejector Pressure (psig) P_e
25B	0.433	99.7	22.6	0.040	0.70	1.28	13.0
25C	0.763	91.2	3.9	0.009	0.74	1.06	17.0
25D	0.963	-	-	-	0.80	1.00	22.3
25E	1.194	30.4	18.4	0.390	0.74	0.89	26.3
25F	1.419	29.5	24.5	0.550	0.73	0.85	32.3
27B	0.406	32.5	29.8	0.55	0.665	1.10	12.0
27C	0.869	27	60.2	1.61	0.600	0.96	17.2
28C	0.806	-	-	-	0.76	1.12	18.0
28D	0.938	-	-	-	0.78	1.10	21.5
28E	1.125	-	-	-	0.805	1.10	25.4
28F	1.375	28.6	89.9	2.15	0.665	0.90	30.5
29D	0.951	-	-	-	0.825	1.22	22.4
29E	1.188	-	-	-	0.850	1.15	27.3
29F	1.357	-	-	-	0.810	1.05	31.2
29G	0.713	-	-	-	0.780	1.00	35.0
30C	0.732	73.0	17.3	0.06	0.80	1.170	17.0
30D	1.044	28.5	48.0	1.16	0.66	0.925	22.0
30E	1.220	27.0	53.2	1.43	0.63	0.88	26.0

TABLE 3. FLOOR PRESSURES (psig) FOR 2-D TESTS

Test # & Section	Floor Pressure Taps									
	1	2	3	4	5	6	7	8	9	10
1A	0	0	0	.1	.22	.14	.30	.24	.44	.52
1C	0	-.03	-.03	.25	.30	.20	.38	.30	.54	.54
1E	0	-.03	-.03	.16	.22	.16	.30	.21	.40	.58
2A	0	-.03	-.10	.16	.17	.10	.17	.16	.28	.32
2B	-.03	-.01	-.06	.13	.17	.10	.19	.16	.28	.31
2C	-.02	-.01	-.03	.10	.12	.10	.16	.12	.22	.30
2D	-.02	-.03	-.05	.10	.14	.10	.17	.14	.26	.32
2E	-.03	-.02	-.03	.10	.13	.10	.18	.14	.28	.36
4A	0	0	0	.02	.03	0	.12	.16	.30	.37
4B	0	0	-.01	.02	.08	.02	.20	.27	.50	.58
4C	0	0	.02	.02	.10	.04	.27	.34	.62	.73
4D	0	.01	0	.08	.2	.1	.33	.30	.56	.66
4E	0	0	0	.10	.21	.10	.31	.30	.52	.66
4F	0	0	0	.10	.22	.10	.30	.28	.51	.66
5C	0	0	0	0	0	0	.09	.36	.53	.53
5D	.01	-.02	0	.11	.2	.1	.37	.47	.78	.9
5F	-.02	.01	0	.14	.24	.10	.30	.35	.60	.70
6C	0	-.03	-.18	.08	.2	.03	.18	.32	.54	.6
6D	-.04	0	-.17	.10	.22	.08	.26	.33	.57	.66
6E	-.06	0	-.18	.10	.22	.10	.29	.32	.58	.66
6F	0	-.07	-.18	.10	.22	.10	.30	.35	.59	.69

TABLE 3. FLOOR PRESSURES (psig) FOR 2-D TESTS (continued)

Test # & Section	Floor Pressure Taps 1	2	3	4	5	6	7	8	9	10
7C	-.02	-.01	-.60	.4	.66	.80	.80	.80	.80	.80
7D	-.13	-.03	-.50	.44	.69	.80	.80	.80	.80	.80
8C	-.04	-.02	-.65	.30	.74	.74	.74	.74	.74	.74
8F	-.07	-.02	-.70	.30	.76	.76	.76	.76	.76	.76
10B	-.02	-.07	-.25	.68	.70	.70	.70	.70	.70	.70
10C	-.05	-.02	-.25	.45	.50	.52	.52	.52	.52	.52
10D	-.10	-.02	-.2	.4	.48	.50	.50	.50	.50	.50
10E	-.10	-.03	-.20	.40	.48	.51	.51	.52	.52	.52
10F	-.05	-.15	-.30	.50	.52	.55	.55	.55	.55	.55
11B	0	-.02	-.30	.80	.81	.81	.81	.81	.81	.81
11C	0	0	-.35	.83	.84	.84	.84	.84	.84	.84
11D	-.10	0	-.20	.58	.62	.63	.65	.65	.65	.65
11E	0	-.10	-.18	.52	.60	.60	.60	.62	.62	.63
12C	-.10	-.02	-.40	.70	.72	.72	.72	.72	.72	.72
12D	-.04	-.14	-.24	.52	.56	.58	.55	.55	.56	.56
12E	-.04	-.14	-.30	.45	.52	.55	.55	.55	.55	.55
13B	0	-.10	-.30	.30	.70	.78	.79	.79	.79	.79
13C	-.02	-.40	+.80	.82	.84	.85	.85	.85	.85	.85
13D	-.03	-.40	0	.80	.81	.82	.82	.82	.82	.82
13E	0	-.25	-.18	.62	.66	.68	.69	.70	.70	.70
13F	0	-.20	-.16	.60	.62	.65	.67	.67	.67	.67

TABLE 3. FLOOR PRESSURES (psig) FOR 2-D TESTS (continued)

Test # & Section	Floor Pressure Taps									
	1	2	3	4	5	6	7	8	9	10
14D	-.30	-.02	-.33	.70	.72	.73	.73	.74	.74	.75
14E	-.03	-.22	-.13	.72	.74	.75	.75	.75	.75	.75
14F	-.31	-.03	-.10	.72	.74	.75	.76	.77	.77	.78
15B	-.02	-.05	-.45	-.3	.60	.62	.62	.62	.62	.62
15C	-.23	-.03	-.65	.48	.68	.77	.77	.77	.77	.77
15D	-.52	-.06	-.85	.73	.80	.80	.80	.80	.80	.80
15E	-.07	-.56	-.64	.77	.80	.80	.80	.81	.81	.81
15F	-.06	-.60	-.15	.76	.80	.80	.81	.81	.81	.81
16D	-.02	-.11	-.45	.10	.50	.61	.63	.63	.63	.63
16E	-.20	-.60	.50	.66	.70	.70	.70	.70	.70	.70
16F	-.28	-.02	-.62	.60	.70	.73	.73	.73	.74	.74
17B	-.10	-.02	-.09	.50	.53	.59	.60	.60	.60	.60
17C	-.03	-.13	-.13	.71	.70	.70	.70	.70	.70	.70
17D	-.06	-.17	.05	.75	.74	.74	.74	.74	.74	.74
17E	-.25	-.06	-.05	.66	.65	.65	.65	.65	.65	.65
17F	-.02	-.20	-.06	.61	.62	.62	.62	.62	.62	.62
18D	-.05	-.10	-.62	.70	.74	.75	.77	.77	.77	.77
18E	-.11	-.03	-.67	.61	.66	.68	.68	.68	.68	.68
18F	-.25	-.08	.71	.75	.75	.75	.75	.75	.75	.75
19E	-.02	-.11	-.5	.72	.74	.75	.75	.75	.75	.75

TABLE 3. FLOOR PRESSURES (psig) FOR 2-D TESTS (continued)

Test # & Section	Floor Pressure Taps									
	1	2	3	4	5	6	7	8	9	10
19F	-.12	-.02	-.4	.71	.73	.73	.73	.73	.73	.73
20B	-.15	-.02	-.30	.63	.65	.65	.65	.65	.65	.65
22C	-.08	-.02	-.28	.50	.54	.55	.55	.55	.55	.55
23B	-.02	-.03	-.48	.65	.66	.67	.67	.67	.67	.67
23C	0	-.04	-.15	.43	.49	.51	.52	.52	.53	.53
24B	-.04	-.10	-.28	.44	.48	.49	.50	.50	.50	.50
24C	-.13	-.05	-.25	.38	.42	.44	.46	.48	.47	.46
24D	-.06	-.13	-.23	.32	.40	.43	.45	.45	.45	.45
25B	-.02	-.04	-.48	.60	.67	.68	.68	.68	.68	.68
25C	-.04	-.11	-.62	.64	.68	.69	.69	.69	.69	.69
25D	-.13	-.04	-.65	.70	.71	.71	.72	.72	.72	.72
25E	-.17	-.08	-.62	+.61	.64	.64	.64	.64	.64	.64
25F	-.08	-.19	-.48	.59	.61	.61	.61	.61	.61	.61
28C	0	0	.25	.72	.75	.75	.75	.76	.78	.79
28D	0	0	.29	.71	.74	.76	.77	.77	.77	.77
28E	0	0	.30	.71	.74	.77	.78	.78	.78	.79
28F	-.11	-.03	-.01	.50	.56	.58	.58	.58	.58	.58
29D	0	-.02	.20	.74	.78	.78	.78	.78	.78	.78
29E	0	0	.26	.73	.78	.78	.78	.78	.78	.78
29F	0	0	.26	.68	.71	.72	.74	.75	.75	.75

TABLE 3. FLOOR PRESSURES (psig) FOR 2-D TESTS (concluded)

Test # & Section	Floor Pressure Taps									
	1	2	3	4	5	6	7	8	9	10
29G	-.02	-.01	.13	.62	.66	.68	.68	.68	.68	.68
30C	-.10	0	-.17	.78	.79	.79	.79	.79	.79	.79
30D	-.12	-.04	-.22	.56	.58	.58	.58	.58	.58	.58
30E	-.12	-.04	-.22	.48	.54	.57	.58	.58	.58	.58

TABLE 4. FULL-SCALE TEST DATA

Test # & Section	Cushion Pressure (psig) P_c	Trunk Pressure (psig) P_t	Fan Pressure (psig) P_{fp}	Cushion Flow Rate (lbm/sec) $\dot{m}_c$	Comments
60-6F	0.000	1.450	0.0	0.0	
60-6E	0.462	1.100	50.0	5.45	
60-6D	0.460	1.075	67.0	6.24	
60-6C	0.460	1.075	84.0	6.80	
60-6B	0.462	1.40	84.0	6.80	P_t increased
60-6A	0.462	1.45	85.0	6.83	
62-8G	0.475	1.125	42.0	4.98	
62-8F	0.475	1.100	59.0	5.91	
62-8E	0.487	1.100	78.0	6.63	
62-8D	0.425	1.175	78.0	6.63	Left wing down
62-8C	0.425	1.125	78.0	6.63	Right wing down
62-8B	0.512	1.110	78.0	6.63	
62-8A	0.525	1.650	78.0	6.63	P_t increased
63-9F	0.462	1.175	50.0	5.45	
63-9E	0.475	1.175	66.0	6.21	
63-9D	0.375	1.200	66.0	6.21	Right wing down
63-9C	0.350	1.225	66.0	6.21	Left wing down
63-9B	0.487	1.125	84.0	6.80	

TABLE 4. FULL-SCALE TEST DATA (concluded)

Test # & Section	Cushion Pressure (psig) P_c	Trunk Pressure (psig) P_t	Fan Pressure (psig) P_{fp}	Cushion Flow Rate (lbm/sec) $\dot{m}_c$	Comments
63-9A	0.487	1.600	84.0	6.80	P_t increased
64-10F	0.487	1.250	50.0	5.45	
64-10E	0.387	1.225	66.0	6.21	Right wing down
64-10D	0.362	1.250	66.0	6.21	Left wing down
64-10C	0.500	1.175	66.0	6.21	
64-10B	0.500	1.175	84	6.80	
64-10A	0.510	1.56	84.0	6.80	P_t increased
66-12D	0.475	0.925	50.0	5.45	
66-12C	0.475	0.925	66.0	6.21	
66-12B	0.475	0.950	84.0	6.80	
66-12A	0.480	1.300	84.0	6.80	P_t increased

TABLE 5. FULL-SCALE FLUTTER DATA

Test # & Section		Accelerometer Stations						
		2	4	6	8	10	12	14
60-6E	f	27.99	27.99	27.99	27.99	27.99	27.99	29.27
	G	0.474	0.677	1.21	2.25	1.94	2.84	0.352
	Amp	0.017	0.024	0.042	0.079	0.069	0.100	0.011
60-6D	f	29.27	27.99	27.99	26.72	26.72	26.72	26.72
	G	0.644	0.667	2.91	11.40	17.30	9.86	4.25
	Amp	0.021	0.024	0.103	0.442	0.670	0.382	0.165
60-6C	f	26.72	26.72	29.27	26.72	26.72	26.72	26.72
	G	3.46	3.18	4.31	11.70	17.50	15.20	4.58
	Amp	0.134	0.123	0.139	0.454	0.678	0.589	0.178
60-6B	f	27.99	27.99	27.99	27.99	27.99	27.99	27.99
	G	6.06	4.90	24.60	24.50	29.30	24.80	13.40
	Amp	0.214	0.173	0.869	0.866	1.035	0.876	0.473
62-8G	f	27.99	27.99	27.99	26.72	26.72	29.27	26.72
	G	0.219	0.285	0.419	1.23	1.89	2.05	0.589
	Amp	0.008	0.010	0.014	0.047	0.073	0.066	0.023
62-8F	f	26.72	26.72	26.72	26.72	26.72	26.72	26.72
	G	1.92	2.69	11.7	10.5	17.8	11.8	8.62
	Amp	0.074	0.104	0.453	0.407	0.690	0.457	0.337

TABLE 5. FULL-SCALE FLUTTER DATA (continued)

Test # & Section		Accelerometer Stations						
		2	4	6	8	10	12	14
62-8E	f	26.72	26.72	26.72	26.72	26.72	26.72	26.72
	G	3.12	2.67	15.8	12.0	19.7	17.1	10.7
	Amp	0.121	0.104	0.613	0.465	0.763	0.663	0.415
62-8D	f	21.63	21.63	21.63	22.90	22.90	--	21.63
	G	4.01	5.35	7.14	6.78	5.66	--	6.34
	Amp	0.242	0.316	0.422	0.358	0.299	--	0.375
62-8C	f	22.90	22.90	22.90	22.90	22.90	22.90	22.90
	G	5.93	5.06	31.2	37.4	32.5	18.5	21.6
	Amp	0.313	0.267	1.647	1.974	1.715	0.976	1.14
62-8B	f	25.45	26.72	25.45	25.45	25.45	25.45	25.45
	G	2.36	2.47	10.8	8.88	13.4	14.6	7.04
	Amp	0.101	0.096	0.462	0.379	0.573	0.624	0.301
62-8A	f	29.27	29.27	29.27	29.27	29.27	29.27	29.27
	G	4.45	3.90	17.40	19.90	27.50	28.10	16.10
	Amp	0.144	0.126	0.562	0.643	0.888	0.908	0.520
63-9F	f	27.99	27.99	27.99	27.99	27.99	29.27	29.27
	G	0.268	0.213	0.551	1.20	1.95	8.70	0.420
	Amp	0.009	0.007	0.019	0.042	0.069	0.281	0.014

AD-A038 559 AIR FORCE FLIGHT DYNAMICS LAB WRIGHT-PATTERSON AFB OHIO F/G 1/3
AN EXPERIMENTAL INVESTIGATION OF TRUNK FLUTTER OF AN AIR CUSHIO--ETC(U)
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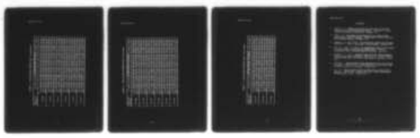

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TABLE 5. FULL-SCALE FLUTTER DATA (continued)

Test # & Section		Accelerometer Stations						
		2	4	6	8	10	12	14
63-9E	f	27.99	27.99	27.99	27.99	27.99	27.99	27.99
	G	2.01	2.68	12.40	10.30	19.00	20.50	8.98
	Amp	0.007	0.095	0.438	0.368	0.671	0.724	0.317
63-9D	f	22.90	22.90	22.90	22.90	22.90	22.90	22.90
	G	8.08	8.89	41.00	43.00	36.80	19.10	27.10
	Amp	0.426	0.469	2.16	2.27	1.94	1.008	1.43
63-9C	f	22.90	22.90	21.63	21.63	21.63	21.63	21.63
	G	1.18	1.87	2.10	1.85	1.07	13.5	4.36
	Amp	0.062	0.098	0.124	0.109	0.063	0.798	0.258
63-9B	f	26.72	26.72	26.72	26.72	26.72	26.72	26.72
	G	3.10	3.10	15.10	14.80	23.20	23.50	9.78
	Amp	0.120	0.117	0.585	0.573	0.899	0.911	0.379
63-9A	f	29.27	29.27	29.27	29.27	29.27	29.27	29.27
	G	3.48	2.40	13.90	18.50	25.90	29.50	14.20
	Amp	0.112	0.077	0.449	0.597	0.836	0.953	0.459
64-10F	f	27.99	27.99	27.99	27.99	27.99	27.99	27.99
	G	0.296	0.480	1.04	1.97	2.66	2.32	0.242
	Amp	0.010	0.017	0.037	0.070	0.094	0.082	0.009

TABLE 5. FULL-SCALE FLUTTER DATA (continued)

Test # & Section		Accelerometer Stations						
		2	4	6	8	10	12	14
64-10E	f	22.90	22.90	22.90	22.90	22.90	22.90	22.90
	G	8.70	9.31	40.10	40.40	34.60	18.60	25.40
	Amp	0.459	0.491	2.11	2.13	1.83	0.981	1.34
64-10D	f	22.90	22.90	22.90	22.90	22.90	22.90	22.90
	G	2.08	2.89	2.11	2.03	0.967	1.82	4.07
	Amp	0.104	0.153	0.111	0.107	0.050	0.096	0.214
64-10C	f	26.72	26.72	26.72	26.72	26.72	26.72	26.72
	G	1.39	2.35	9.86	12.00	18.30	13.90	7.10
	Amp	0.054	0.091	0.382	0.465	0.709	0.539	0.275
64-10B	f	26.72	26.72	26.72	26.72	26.72	26.72	26.72
	G	2.44	2.39	13.20	15.90	22.50	18.40	10.20
	Amp	0.095	0.093	0.512	0.616	0.872	0.713	0.395
64-10A	f	29.27	29.27	29.27	29.27	29.27	29.27	29.27
	G	4.53	4.12	23.40	30.70	35.40	32.30	20.50
	Amp	0.146	0.133	0.756	0.992	1.14	1.04	0.662
66-12D	f	27.99	27.99	27.99	27.99	27.99	27.99	27.99
	G	0.536	0.470	1.28	2.57	4.57	4.51	1.17
	Amp	0.019	0.017	0.045	0.091	0.161	0.159	0.041

TABLE 5. FULL-SCALE FLUTTER DATA (concluded)

Test # & Section		Accelerometer Stations						
		2	4	6	8	10	12	14
66-12C	f	26.72	26.72	26.72	26.72	26.72	26.72	26.72
	G	2.30	1.70	11.50	14.00	18.30	16.70	9.58
	Amp	0.089	0.066	0.446	0.542	0.709	0.647	0.371
66-12B	f	26.72	26.72	26.72	26.72	26.72	26.72	26.72
	G	2.98	2.73	16.80	16.10	20.20	19.50	11.70
	Amp	0.116	0.106	0.651	0.624	0.783	0.756	0.454
66-12A	f	27.99	27.99	27.99	27.99	27.99	27.99	27.99
	G	5.99	4.95	25.80	30.00	35.00	32.30	24.70
	Amp	0.212	0.175	0.912	1.06	1.24	1.14	0.873

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